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Household Water Conservation and Wastewater Flow Reduction

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HOUSEHOLD WATER CONSERVATION AND WASTEWATER FLOW REDUCTION

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Abstract

Studies the legal and economic aspects of devices and policies to reduce water and wastewater flows. After reviewing the literature, the report considers building and plumbing codes from selected areas to see whether or not they provide constraints on the introduction of water-saving devices; and considers state laws to see whether they permit pricing schemes which encourage conservation. A computer model is developed, using water demand functions and cost functions from the literature, to determine the benefits to consumers and producers of various pricing systems. Through use of a second computer model, benefits are calculated for various replacement strategies in the adoption of water-saving devices.

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CHAPTER ONE

INTRODUCTION

This report is the result of a study performed by Energy Resources Co. Inc., under contract to the U.S. Environmental Protection Agency.

The study investigates the cost-effectiveness of water-saving options contributing to the reduction of wastewater flows from households. The water-saving options analyzed include household water-conserving devices, metering and pricing schemes, as well as local ordinances and national policies. Two other studies sponsored by EPA have analyzed the savings resulting from the use of some of the household water-saving devices.[1,2] One of these studies is the basis for a report to the 93rd Congress, which was done pursuant to Section 104 (0) (2), P.L. 92-500, indicating that concern exists in Congress for household water conservation and wastewater flow reduction.[3]

Concern for household water conservation and wastewater flow reduction is fully justified. A major part of public water supplies is used by residential consumers.[4] Similarly,

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[1] J. R. Bailey, et al., A Study of Flow Reduction and Treatment of Wastewater from Households. (Groton, Conn: General Dynamics, Electric Boat Division, 1969).

[2] S. Cohen and H. Wallman, Demonstration of Waste Flow Reduction from Households. (Groton, Conn: General Dynamics, Electric Boat Division, 1974).

[3] Reduction in Water Consumption and Flow of Sewage, Report to the Congress, EPA, June 1974.

[4] The literature does not reveal an agreed-upon number but data from the Handbook of Environmental Control indicates 68 percent of public water supplies goes to domestic (i.e., residential and public) uses. Richard G. Bond, Conrad P. Straub, and Richard Prober, ed., CRC Handbook of Environmental Control, Volume III: Water Supply and Treatment, CRC Press, Cleveland, Ohio, p. 148.

a large part of the wastewater flow handled by municipal sewage treatment plants is residential wastewater. [1] Reduction of domestic water consumption and the resulting wastewater flow reduction would effect savings in operating costs and capacity expansion of municipal waste treatment plants.

This study not only investigates the cost-effectiveness of household water-saving devices, but also that of metering and pricing schemes for different types of housing units, both regionally and nationally. The conclusions of this study should suggest policy guidelines for the metering of different types of housing units and for estimating the benefits of mandatory municipal water conservation and wastewater flow reduction measures prior to any application for Federal grants and/or subsidies for waste treatment plant expansions.

1.1 Organization of the Report

This report is organized into six chapters and two appendices. Chapter Two summarizes the results of the project and presents recommendations. Chapters Three and Four present the findings of the literature reviews. Chapter Three discusses water use patterns, water-saving devices, pricing schemes, public acceptance of water-saving methods, and infiltration and inflow, and Chapter Four discusses legal constraints and ramifications of water-saving methods. Chapters Five and Six describe the two computer programs used in the study and discuss their assumptions and results.

Appendix A is a discussion of the relationships between waste concentrations and waste treatment efficiency.

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[1] According to a recent estimate, residential wastewater is 45% of the average daily flow to municipal sewage treatment plants, industrial and commercial flow is 30% and the residual (infiltration and storm flows) is 25%. (Clean Water Report to Congress - 1975-76, EPA, forthcoming).

CHAPTER TWO

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

2.0 Project Goal

This project examined the costs and benefits of various methods of reducing wastewater flow from households. Wastewater flow is closely related to potable water use; by decreasing water use, wastewater flow will also be reduced. Consequently, this report is concerned with methods for reducing water use including water-saving devices, pricing schemes, public education, modification of building codes and local plumbing ordinances, and water recycling.[1]

Two computer programs were developed to evaluate the costs and benefits of the various methods of reducing household water use. The first determines the costs and benefits of water-saving devices and plumbing fixtures, while the second evaluates different pricing schemes for their efficiency, discriminatory effects, and water conservation effectiveness.

The project consisted of two phases: a literature review and the development of computer analysis models.

2.0.1 Phase 1-Literature Review

Technical journals and institutional reports were reviewed to determine household water use patterns, factors affecting water demand, existing water-saving devices, the pros and cons of different pricing schemes, public acceptance of water-saving methods, and the cost of water and wastewater treatment and distribution.

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[1] Although water recycling is an interesting concept, it was not given much emphasis in this study due to the expense of implementation and the fact that it is more efficient to continue treating - and perhaps recycling - water on a collective rather than an individual basis. For information on the expense of implementation, see J. Bailey and H. Wallman, "Flow Reduction of Wastewater from Households," Water and Sewage Works, March 1971.

Government sources were also consulted. Government publications were studied and knowledgeable people from the following agencies were interviewed: the Environmental Protection Agency, the Federal Housing Administration, the Department of Defense, the National Bureau of Standards, the Washington Suburban Sanitary Commission, and others. In addition, water-saving device manufacturers were contacted to obtain current prices and water-saving data.

Finally, the literature concerning legal and institutional constraints upon the implementation of household flow reduction programs was reviewed. The programs subject to these controls include the installation of water-saving devices, the water recycling toilet, and the implementation of metering, pricing, and user service charges. Building and plumbing codes, and legislative controls on water and sewage departments were also examined.

2.0.2 Phase 2-Mathematical Model Formulation

Two computer programs were developed. The engineering economy analysis model (EEAM) evaluates the cost-effectiveness of water-saving devices and the associated cost savings in water and waste treatment plants. Two different device replacement strategies were compared with the strategy of replacing current devices with the same type when the current ones are worn. The two strategies considered were: (a) replace all devices immediately with water-saving ones, and (b) replace with water-saving devices only when existing ones wear out. For each strategy, three different utility rates (unit water and sewer service price) were considered. The policy analysis model (PAM) evaluates the discriminatory effects and economic efficiency of various pricing schemes. For each pricing scheme, three different utility rate schedules (low, medium and high) were considered, and these evaluations in terms of the PAM were conducted for two cases of average cost function: decreasing and increasing ones.

2.1 Water Use Patterns, Technology and Pricing Schemes

This section presents highlights of results from the literature review phase. Details are in Chapter Three.

The literature indicated that average water use in the United States is 338 liters/person/day [89 gal. per capita/day (gpcd)], ranging from 76 liters/person/day (20 gpcd) to over 2270 liters/person/day (600 gpcd). The three major components of water use are lawn sprinkling, toilet flushing, and bathing. Water usage does not occur at a constant rate but displays hourly and seasonal peaks, with usage high in the morning and evening, and higher during the summer months than during the winter months. Factors that influence the level of water usage include the price of water, the user's income, climate, and the size of lawn that requires sprinkling. Methods of saving water are the installation of water-saving devices such as dual cycle toilets, water conserving shower heads and faucet aerators in both old and new construction, changing water use habits, repairing leaks, and reducing water pressure.

This literature review suggested that there are six pricing schemes which would represent most of the actual rate schedules, They are flat rates, decreasing block rates, uniform unit price, increasing block rate, seasonal rates and hourly peak rates.[1] These were evaluated in terms of economic efficiency, distributional effects, revenue producing ability, administrative simplicity, and water conservation. Results indicated that there is no pricing scheme that is considered to be superior with respect to these criteria. Consequently the choice of a pricing policy is not apparent.

The literature review also indicated that the success of any water-saving program is influenced by the public's acceptance of the program. Generally, there is a favorable response to programs promoting the installation of water-saving devices and to public education programs. The public is opposed to price increases and has mixed reactions about the reuse of treated wastewater. Low contact use of wastewater such as lawn sprinkling are acceptable but higher contact uses such as drinking and bathing often meet with public disapproval.

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[1] A flat rate is an annual or monthly fixed charge. A decreasing block rate is a pricing scheme where the charge per additional unit of water decreases as the quantity of water consumed increases. A uniform unit charges the same unit price for each unit of water used. Increasing block rates are like decreasing blocks, exept that the charge per additional unit of water increases with volume. Seasonal rates charge more for water during the summer months than during the winter months. Hourly peak rates charge more for water during hours of peak usage than during the rest of the day.

2.2 Institutional Problems

This section highlights the results of the investigation of the legal and institutional constraints upon the implementation of household wastewater flow reduction programs. The legal and institutional problems are concerned with constraints on installing water-saving devices in homes, constraints on implementing pricing schemes, and the possibility of cross-connections if water-recycling toilets are installed. Most water-saving devices would not be in violation of building and plumbing codes. However, some codes may have to be changed to permit the installation of dual cycle and water-saving toilets. States and municipalities have set various restrictions on the use of utility revenues; therefore, pricing schemes must be carefully designed to comply with existing legislation, or legislation must be changed. Building authorities will allow the use of the water-recycled toilet only if engineering technology can solve the problems of cross-connections and sanitary conditions (see Chapter Four for details).

2.3 Computer Analysis

Results of the computer analysis are discussed in this section. These results should be interpreted only in the context of the particular models considered in Chapters Five and Six. Evaluations of water-saving devices will be presented first, to be followed by the results on economic efficiency of pricing schemes.

Tables 2-1 and 2-2 are summaries of results from the EEAM pertaining to the costs and benefits of water-saving devices. Total national savings are defined as the savings in water supply and sewage treatment costs (where these costs are given by functions which vary by region of the country), less the cost of the devices. Those devices that offer net national savings are flow-limiting shower heads, dual cycle and low consumption toilets, and toilet inserts. Alternatively, savings are calculated assuming certain constant values for the incremental cost of water and sewage service, to obtain the estimates labelled "household savings." These calculations, also shown in Tables 2-1 and 2-2, show a similar pattern of cost savings for the devices.

Table 2-3 summarizes the literature review results pertaining to public acceptance and legal or institutional constraints associated with the installation of these water-saving devices or options, as well as public education campaigns. In particular the option of recycling wastewater from laundry and bathing for toilet flushing is not received favorably by the public, and faces severe legal and institutional constraints.

From the analysis of water-saving devices, dual cycle toilets, flow-limiting shower heads, toilet inserts, and water saving water closets are generally cost-effective. As a result, installing these devices should be encouraged.

The methods of reducing wastewater flow discussed in this study reduce the volume of flow but not the amount of waste carried. As a result, waste concentration may well increase. Nonetheless, cost savings through the postponement of plant expansion will occur because of the reduced volume of sewage. Additional savings may also occur if increased concentration improves plant efficiency either by increasing the percent removal of wastes or by reducing the time necessary for treatment. However, preliminary analysis does not seem to indicate any cost savings of this type in secondary and advanced treatment. Savings can only be achieved in primary treatment (see Appendix A). However, more rigorous research is needed to clarify this question in the future.

It is not apparent from this analysis which of the six rate structures is superior. A judgment about these rate structures would depend on the detailed designs (e.g., levels and block sizes) and the type of rate (e.g., increasing block or decreasing block rates) under consideration. But the analysis in this project showed that with the cost functions considered in this study, any of those flow-based charges (increasing block

TABLE 2-1

TOTAL SAVINGS[a] FOR STRATEGY S_1[b] IN MILLIONS OF DOLLARS FOR TEN YEARS FOR LOW, MEDIUM AND HIGH UTILITY RATES

DEVICE	TOTAL NATIONAL DOLLAR SAVINGS	TOTAL HOUSEHOLD SAVINGS		
		LOW RATE[c]	MEDIUM RATE[d]	HIGH RATE[e]
Faucet Aerators	- 2,121	- 2,718	- 1,982	5,375
Thermostatic Mixing Values	-17,930	-21,977	-17,025	32,499
Flow-limiting Shower Heads	8,167	845	9,730	98,575
Dual Cycle Water Closet	9,048	- 934	11,095	131,380
Vacuum Flush Toilet	-74,500	-86,500	-72,110	72,286
Toilet Insert	6,414	107	7,780	84,513
Recycling of Wastewater for Toilet Flushing	-15,359	-32,081	-12,332	185,150

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[a] Rounded off to the nearest million

[b] S_1 is the strategy of immediate replacement with water-saving devices

[c] \$0.10/thousand gallons

[d] \$1.00/thousand gallons

[e] \$10.0/thousand gallons

TABLE 2-2

TOTAL SAVINGS[a] FOR STRAGEGY S_2[b]

IN MILLIONS OF DOLLARS FOR TEN YEARS FOR LOW, MEDIUM AND HIGH UTILITY RATES

DEVICE	TOTAL NATIONAL DOLLAR SAVINGS	TOTAL HOUSEHOLD SAVINGS		
		LOW RATES[c]	MEDIUM RATES[d]	HIGH RATES[e]
Faucet Aerators	- 266	- 369	- 242	1,032
Thermostatic Mixing Values	-4,258	- 4,952	- 4,094	4,478
Flow-limiting Shower Heads	2,366	202	2,862	29,461
Dual Cycle Water Closet	1,924	230	2,312	23,134
Water Saving Water Closet	991	34	1,216	13,031
Vacuum Flush Toilet	-17,748	-19,786	-17,287	7,707
Toilet Insert	1,618	541	1,870	15,152
Recycling of Wastewater for Toilet Flushing	-5,037	- 7,806	- 4,428	29,349

[a] Rounded off to the nearest million

[b] S_2 is the strategy of replacement with water-saving devices when the original devices wear out.

[c] \$0.10/thousand gallons

[d] \$1.00/thousand gallons

[e] \$10.0/thousand gallons

TABLE 2-3

SUMMARY OF RESULTS ON PUBLIC ACCEPTANCE AND LEGAL CONSTRAINTS PERTAINING TO WATER-SAVING DEVICES

	Public Acceptance *	Legal Constraints *
Faucet Aerators	+	+
Thermostatic Mixing Valves	NA *	0
Flow-limiting Shower Heads	+	+
Dual Cycle Toilets	0	0
Water Saving Toilets	0	0
Vacuum Flush Toilets	NA	0
Toilet Inserts	+	0
Recycling for Flushing	0	–
Public Education	+	+

* NA = no data available
+ = favorable response
– = unfavorable response
0 = mixed response

rates, decreasing block rates, and uniform unit rates) could lead to economically efficient outcomes, since any one of these pricing schemes could be designed to produce prices at the margin equal to incremental cost. However, one conclusion is obvious: flat rates should not be used if economic efficiency and distributional effects are the basic criteria. Unfortunately, the proper choice of rate structures is not clear, because the decision is influenced by various local situations including the shape of the average cost function. If the average cost function is rising, increasing block rates may be a good option. It will permit the utility to use marginal cost pricing without surpassing the profit limitations ofter placed on utilities. On the other hand, a decreasing cost function would favor the choice of decreasing block rate, while in some localities the uniform unit rates would be preferable. For the cost curves used in the analysis, the welfare maximizing marginal price of water and sewer services is in the vicinity of 35 to 40 cents/ thousand gallons. It should be noted, however, that these results are predicated on the assumption that the relative shape of the utility system load curve remains constant so that the same average cost function can be used to estimate capacity expansion costs. Should the shape of load curves shange, the complicated peak load pricing problem would have to be analyzed. Moreover, other factors like seasonal demands and a more explicit distinction between water and sewer prices have not been considered in this analysis. A more rigorously designed research project would need to include all these factors.

2.4 Recommendations

From the Policy Analysis Model, it has been determined that flat rates are not economically efficient. Because flat rates produce discriminatory effects and do not encourage water conservation, they should not be used. The proper choice of a rate structure would depend on the local conditions.

The choice of a rate structure can also be coordinated with a policy of installing water-saving devices. This analysis shows that there are no serious institutional constraints associated with the installation of devices, that the public acceptance of voluntary installation is favorable, and that dual cycle toilets, flow-limiting shower heads, toilet inserts, and water saving water closets offer savings; therefore, the installation of these three devices should be encouraged. Gradually such installations could be mandated and then the proper rate structure could be introduced to achieve economic efficiency.

CHAPTER THREE

LITERATURE REVIEW

3.0 Introduction

This chapter is divided into five sections which discuss the material found in approximately 200 reports, articles and books which were reviewed. Section 3.1 examines water use patterns in households, i.e., the amount of water used by households and the factors which influence this amount. Section 3.2 discusses water-saving devices and other methods of achieving water conservation, their cost, and the economic and water savings that can be achieved. Also dealt with are methods other than hardware devices which can be used to conserve water, including changes in water use habits, leak repair and pressure reduction. Section 3.3 discusses pricing and metering. Section 3.4 considers public acceptance of water-saving devices and water conservation schemes. Section 3.5 deals with infiltration and inflow.

3.1 Water Use Patterns

The literature contains many estimates and much data on the amount of water used in households. This data is compiled in Table 3-1. It is a "best guess" based on the literature reviewed (see the bibliography for this section for a listing of sources).

Average per capita household water use in the United States is estimated to be 243 liter/person/day (64 gpcd). Average sprinkling or outdoor demand is an additional 95 liter/person/day (25 gpcd), bringing the total usage to 338 liter/person/day (89 gpcd); in reality, this usage varies from less than 76 liter/person/day (20 gpcd) to over 2270 liter/person/day (600 gpcd).

Water is not used at a constant rate during the day. Heavy usage occurs in morning and evening peaks. The morning peak occurs between 7:00 a.m. and 9:00 a.m. in the winter and between 8:00 a.m. and 1:00 p.m. in the summer. The

TABLE 3-1

PER CAPITA WATER USE

CATEGORY OF USE	LITERS/ PERSON/DAY	GAL/ CAPITA/DAY*	% OF TOTAL USE
Toilet flushing	95	(25)	39
Bathing and hygiene	84	(22)	34
Laundry	34	(9)	14
Dishwashing	15	(4)	6
Drinking and cooking	11	(3)	5
Miscellaneous cleaning	4	(1)	2
Totals	243	(64)	100

* Gallons/capita/day (gpcd)

evening peak is between 5:00 p.m. and 7:00 p.m. in the winter and 6:00 p.m. and 9:00 p.m. in the summer.[1] Shifts in peaks are largely due to summer sprinkling demands. While the mean of daily use over the year is 1495 liter/day/dwelling unit (395 gal/day/dwelling unit) the mean of peak hourly use, i.e., the mean rate at which water is used during peak periods, is 9728 liters/day/dwelling unit (2570 gal/ day/

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[1] Jerome B. Wolff, "Peak Demands in Residential Areas," Journal American Water Works Association, 53: October 1961 1251.

dwelling unit.)[1] There are seasonal as well as hourly peaks in water usage. Summer demands are approximately 3 to 4 times the amount demand during winter months.[2]

Price, income, climate, average lawn area, and the number of occupants per household all affect how much water is used. A study done at Johns Hopkins University by Linaweaver, Geyer and Wolff[3] is probably the most important work done in the area of household water consumption. The conclusions of this study are that income, climate, and pricing methodsare the most important determinants of water demand. These factors and the other factors mentioned above are discussed below.

3.1.1 Price

In determining water consumption it is important to note whether an area is metered or charged on a flat rate. Because flat rate pricing provides no incentive to conserve water, flat rate usage may be as much as double the usage in metered areas. Figure 3-1 further illustrates this point. Meters were installed throughout the Boulder, Colorado area during a time period short enough so that factors such as income, climate and type of housing could be considered constant. The American Water Works Association (AWWA) committee report cites several examples of increased price causing decreased demand.[4]

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[1] F.P. Linaweaver, Jr., John C. Geyer, and Gerome B. Wolff, "Summary Report on the Residential Water Use Research Project," Journal American Water Works Association (March 1967): 269.

[2] Linaweaver, "Residential Water Use," 270.

[3] Linaweaver, "Residential Water Use," 270.

[4] American Water Works Association, Committee of Water Use, "Water Use: Committee Report," Journal American Water Works Association (May 1973): 288-289.

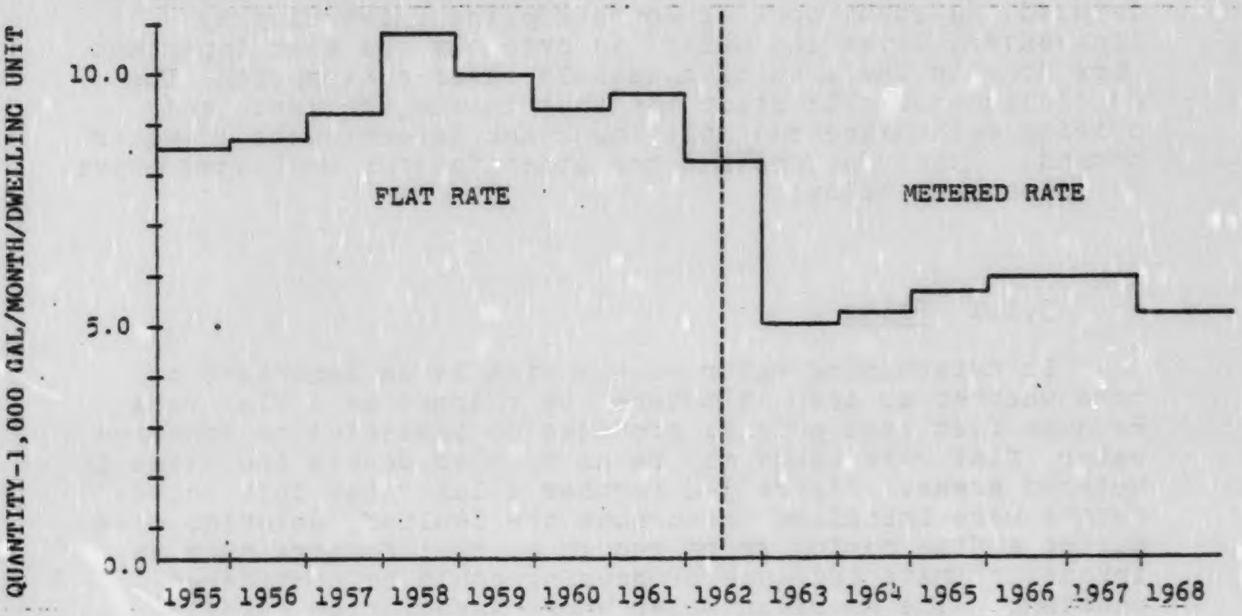

Figure 3-1. This figure shows in-house water use before and after metering. (Steve H. Hanke and John J. Boland, "Water Requirements or Water Demand?" Journal American Water Works Association (November 1971): 679.)

3.1.2 Income

Studies by Headley, Larson and Hudson, Bogue, and Linaweaver, Geyer and Wolff[1] report an increase in water demand as a function of increase in income. This can be attributed to increased use of swimming pools, bathrooms, cars, washing machines, dishwashers, garbage disposers, water picks for dental care, water-cooled air conditioners, other water-using devices, and the likelihood of larger lawn areas to irrigate.

3.1.3 Climate

The influence of climate on water demand can be seen in the increase of water use during hot, dry months. This increase is mainly attributable to sprinkling uses but is also related to bathing and water-cooled air conditioner demands.

An AWWA[2] report states that climate is especially important in areas that receive between 13 and 102 centimeters (5-40 inches) of rain annually. Areas that receive less than 13 centimeters do not depend upon rain for sprinkling purposes, and areas that receive more than 103 centimeters usually have enough rain to keep lawns green. In areas where 13-103 centimeters of rain fall annually, seasonal water demand is inversely related to the season's rainfall.

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[1] J. Charles Headley, "The Relationship of Family Income and Use of Water for Residential and Commercial Purposes in the San Francisco-Oakland Metropolitan Area," Land Economics, 39: 441; B.O. Larson and H.E. Hudson, Jr., "Residential Water Use and Family Income," Journal American Water Works Association (August 1951): 603; S.H. Bogue, "Trends in Water Use," Journal American Water Works Association, 55 (May 1963): 548; R.P. Linaweaver, Jr., John C. Geyer, and Jerome B. Wolff, "Summary Report on the Residential Water Use Research Project," Journal American Water Works Association, 59 (May 1967): 267.

[2] American Water Works Association, "Water Use," 289.

Linaweaver,, Geyer and Wolff[1] demonstrate the relationship in another way by showing that water demand per capita is greater in the arid west than it is in the humid east.

3.1.4 Average Irrigable Area of Lawn

The irrigable area of lawns and gardens in a community influence water demand because this variable, along with the climate, determines the amount of water needed for spinkling.

3.1.5 Number of Occupants per Household

The influence the number of occupants per household has on water demand was studied by Richard A. Andrews and Marsha Hammond.[2] Their sample consisted of 361 households. Their conclusions follow: "There is an 'overhead' quantity of water used in an occupied household, and per capita consumption of water decreased as the number of persons in the household increased . . . The age composition of persons in the household also appeared to influence household consumption of water when considered on an annual basis . . . Children from birth to three years may not materially influence household water consumption; the factor of age, however, shows a greater influence for the older members of the family: adults use the greatest quantity of water."[3]

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[1] Linaweaver, "Residential Water Use," 267.

[2] Richard A. Andrews and Marsha Hammond, Characteristics of Household Water Consumption in Three New Hampshire Communities (New Hampshire University Water Resources Research Center Research Report No. 3 [December 1970]).

[3] Andrews, Household Water Consumption, 10, 17.

TABLE 3- 2

WATER-SAVING DEVICES

DEVICE	LITERS/USE (GAL/USE)	LITERS SAVE/USE (GAL SAVE/USE)	WATER SAVED/(a) PERSON 1 YR - LITERS (GAL)	PURCHASE PRICE OF DEVICE ($)	EXPECTED LIFE OF DEVICE (YEARS)	MANUFACTURER (f)
standard toilet	19 - 26.5(b) (5 - 7)	0	0	50.00	50	Elger
water saving toilet	13.2(c) (3.5)	5.7 - 13.2 (1.5 - 3.5)	7380 - 24190 (1950 - 6390)	40.50(c)	50	Crane
dual cycle toilet, liquid waste	4.7(d) (1.25)	14.2 - 21.8 (3.75 - 5.75)	13500 - 32410 (3570 - 8560)	NA	50	NA
dual cycle toilet, solid waste	9.5(d) (2.5)	9.5 - 17.0 (2.5 - 4.5)	3467 - 6351 (920 - 1680)	NA	50	NA
dual cycle toilet, total savings	NA	NA	16970 - 38760 (4480 - 10240)	NA	NA	NA
dual cycle device, liquid waste	9.5 - 13.2(c (2.5 - 3.5)	9.5 - 13.2 (2.5 - 3.5)	5472 - 25400 (1450 - 6710)	3 - 6	15	Utah Marine
dual cycle device solid waste	19 - 26.5 (c (5 - 7)	0	0	3 - 6	15	Utah Marine
vacuum toilet	1.9(d) (0.5)	17.0 - 24.6 (4.5 - 6.5)	22220 - 44900 (5870 - 11860)	1,115(e)	NA	Liljendahl (Swedish)
urinal	5.7(d) (1.5)	13.2 - 20.8 (3.5 - 5.5)	12420 - 30400 (3280 - 8030)	50	50	Elger
plastic bottle inserts	NA	0.9 - 15.1(c) (0.25 - 4)	1250 - 27630 (330 - 7300)	0	NA	NA
fill valve insert	NA	11.4 (3)	14800 - 20740 (3910 - 5480)	3.50	10	Fillmaster
Little John Insert	NA	7.8 - 11.4(c) (2 - 3)	9880 - 20740 (2610 - 5480)	3.48	10	Ecological Water Products
Little John Insert	NA	7.8 - 11.4(c) (2 - 3)	9880 - 20740 (2610 - 5480)	3.96	10-15	Metropolitan Water Saving Products

DEVICE	LITERS/USE (GAL/USE)	LITERS SAVE/USE (GAL SAVE/USE)	WATER SAVED/ PERSON 1 YR - LITERS (GAL) (a)	PURCHASE PRICE OF DEVICE ($)	EXPECTED LIFE OF DEVICE (YEARS)	MANUFACTURER (f)
Bend float arm	NA	3.8 (1)	4920 - 6890 (1300 - 1820)	0	NA	
standard showerhead	30 - 37.8(b) (8 - 10 gpm)	0	0	10.70	10	American Standard
flow restricting showerhead	13.2 liter/min (3.5 gpm)	17.0-24.6 liter/min (4.5-6.5 gpm)	12420 - 22450(h) (3280 - 5930)	10.70	10	American Standard
flow restricting (g) showerhead with shut off device	9.5 liter/min(c) (2.5 gpm)	20.8-28.4 liter/min (5.5-7.5 gpm)	15220 - 25930(h) (4020 - 6850)	14.95	10	Ecological Water Products
flow restrictive showerhead without shut off device	9.5 liter/min(c) (2.5 gpm)	20.8-28.4 liter/min (5.5-7.5 gpm)	15220 - 25930(h) (4020 - 6850)	11.95	10	Ecological Water Products
flow restrictive showerhead	17.0 liter/min(c) (4.5 gpm)	13.2-20.8 liter/min (3.5-5.5 gpm)	9690 - 19000(h) (2560 - 5020)	35.98	10	Speakman Co.
flow restrictive showerhead	13.2 liter/min(c) (3.5 gpm)	17.0-24.6 liter/min (4.5-6.5 gpm)	12420 - 22450(h) (3280 - 5930)	22.67	10	Speakman Co.
flow restrictive showerhead	9.5 liter/min(c) (2.5 gpm)	20.8-28.4 liter/min (5.5-7.5 gpm)	15220 - 25930(h) (4020 - 6850)	15.52	10	Speakman Co.
aerators	25% of faucet flow	NA	1700 (450)	1.00- 2.50	2	NA
thermostatic mixing valve	30% of faucet & showerhead flow	NA	11470 (3030)	200	50	Ultraflo

TABLE 3-2 (CONT)

Table 3-2 (Notes)

(a) Based upon water usage as tabulated in Table 3-1. Sample calculation using data for the water saving toilet:

$$\frac{95 \text{ liter/person/day}}{19 \text{ to } 26.5 \text{ liter/flush}} \times 365 \text{ day/yr}$$

$$\times (19 \text{ to } 26.9 \text{ liter/flush} - 13.2 \text{ liter/flush})$$

$$= 7380 - 24190 \text{ liter saved/person/year}$$

(b) The Washington Suburban Sanitary Commission, A Consumer Handbook on Water-Saving and Wastewater-Reduction (Washington, D.C.: The Washington Suburban Sanitary Commission, 1970), p.2.

(c) Telephone conservation with manufacturer.

(d) J. Bailey, et al., A Study of Flow Reduction and Treatment of Wastewater from Households (General Dynamics, Electric Boat Division, [1969]).

(e) Cost based on installment in new construction. Installation and purchase cost in old construction is $1,520. (d)

(f) Mention of a commercial product does not imply endorsement or recommendation.

(g) This device allows the shower flow to be shut on and off without necessitating temperature adjustment. It is useful while shampooing hair or "soaping up."

(h) This calculation assumes 84 liters/person/day (20 gpcd) are used in showers and no baths are taken. The savings will be less in proportion to the number of baths that are substituted for showers.

3.2 Water-Saving

3.2.1 Water-Saving Devices

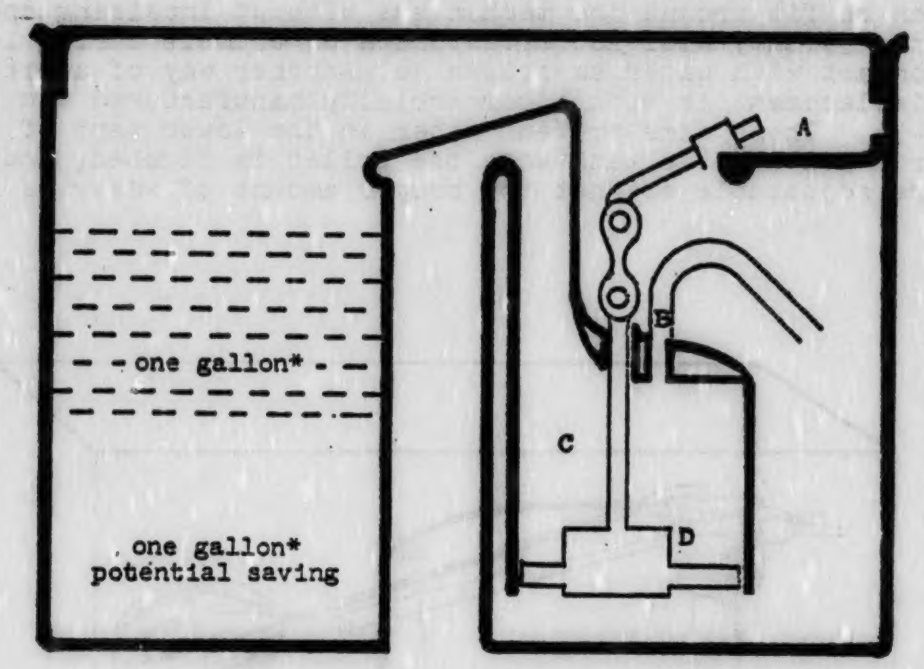
There are several types of hardware available which are capable of achieving water savings with no inconvenience to the user. Hardware designed for toilets, showers, faucets, and washing machines are discussed below. Table 3-2 compares the cost of the devices with their water-saving capabilities.

3.2.1.1 Toilets

There are two approaches to reducing the volume of water used in toilet flushing. The first is purchase of a new toilet and the second is modification of the existing toilet.

Several types of water-saving toilets exist. The one most accepted in the United States looks and operates like the conventional style toilet but is designed to use 13.2 liter/ flush (3.5 gal/flush) compared to the standard 19-26.5 liter/ flush (5-9 gal/flush) models. Another water-saving toilet is the English style dual cycle toilet (Figure 3-2). This toilet uses 4.7 liter/ flush (1.25 gal/flush) for liquid wastes and liter/flush (2.5 gal/flush) is obtained by holding the handle down longer. A vacuum toilet that uses air rather than water for waste transport has also been developed. Because of vacuum requirements, this type of toilet is only practical in large apartment houses with 100 or more units. Urinals have been suggested as a means of saving water. However, objections are numerous: most are only useful for men, they take up added space, and consequently consumer acceptance is poor.

The second method of reducing the wastewater generated from toilets is modification of the toilets. The most common practice is some form of the "Brick" or displacement method. Plastic bottles, filled with water and weighted with a few pebbles are more satisfactory than bricks because:



A-handle, B-air intake, C-siphon, D-piston

* Imperial gal.

Figure 3-2. This figure shows the mechanics of a dual cycle toilet tank. When the piston (D) is held open, the air intake (B) is closed and the whole contents of the tank are siphoned. When the piston is opened, then released, the air intake is open and the siphon breaks when half the tank is empty. (J. Bailey and H. Wallman, "Flow Reduction of Waste Water from Households," Water and Sewage Works (March 1971): 69.)

(1) they are not as heavy as bricks and will not crack the tank; (2) they come in many sizes and shapes (bottles for hand lotion, dishwashing soap, bleach and so on) and thus can be fit around the mechanisms without impairing operation; and (3) they will not deteriorate or crumble during long contact with water as bricks do. Another way of achieving displacement is with a commercially manufactured dam (Figure 3-3). These dams prevent water in the lower part of the tank from leaving the tank when the toilet is flushed, and some are adjustable so that the proper amount of water is released.

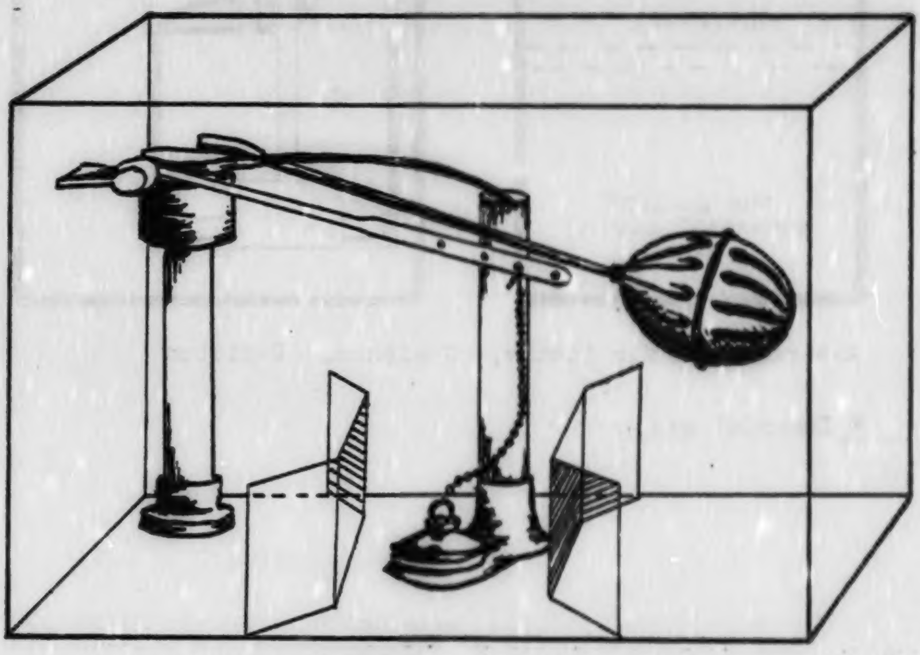


Figure 3-3. This figure shows how dams may be used to conserve water in toilet flushing.

A second form of toilet modification consists of bending the float arm so that water filling the tank is shut off sooner. Caution must be taken while doing this to aviod breaking the arm and incurring unnecessary expense. This method has limitations in that the toilet depends upon water pressure for optimal operation: lowering the water level reduces this pressure and may impair proper operation. For this reason toilet inserts are preferable.

One man in Hyattsville, Maryland suggested attaching a weight to the shaft above the tank ball, forcing the ball to close the tank any time it is not held open and allowing the user to control how much water is used.[1]

3.2.1.2 Showers

Several flow-reducing showerheads are available. They restrict water flow to 10-19 liter/min (2.5-5.0 gal/ min) depending upon the particular fixture. Conventional showerheads operate by aerating and dispersing the water. A showerhead using only 2 liter/min (0.5 gal/min) is planned for marketing in 1975.[2] This showerhead mixes compressed air with water to achieve a satisfying shower.

Shower insert devices are also available. They are placed between the showerhead and waterpipe and restrict flow. For those on a tight budget, the Washington Sanitary Commission suggests placing a one centimeter (3/8") washer between a 1.3 centimeter (1/2") showerhead and the water outlet pipe.

3.2.1.3 Faucets

Water savings from faucets may be achieved by the use of aerators or thermostatic mixing valves. Normal faucet flow is 11-19 liter/min (3-5 gal/min). Most sources maintain that aerators reduce flow by 25 percent. This results in flows of 8.5-14.2 liter/min (2.25-3.75 gal/min). Thermostatic mixing valves automatically mix water to any desired temperature thus saving water that would be wasted while the user adjusts faucets to obtain a certain temperature.

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[1] The Washington Suburban Sanitary Commission, A Customer Handbook on Water-Saving and Wastewater-Reduction (Washington, D.C.: The Washington Suburban Sanitary Commission, 1970): 12.

[2] Telephone interview with Kenneth T. Row, Minuse Systems, Inc., Jackson, California, December 1974.

3.2.1.4 Washing Machines

"Suds savers" - washing machines that save wash water for reuse have been developed, but consumer acceptance is poor since they do not seem to perform as well as other machines. Front-loading washing machines use about half as much water as top-loading machines, but again, consumer acceptance is poor. Washing machines generally use between 32 and 59 gallons of water per wash.[1] It might be expected that the use of washing machines on the lower end of this scale would conserve water, but Consumer Reports[2] observes that a medium to large family may actually save more water by using a high water-using machine and washing more clothes per cycle.

3.2.2 Other Methods of Water Saving

Methods other than hardware devices that reduce water consumption are changes in water use habits, leak repair, water pressure reduction, and the installation of water-saving devices in new construction. This section considers these methods.

Families (and individuals) could save hundreds of liters of water per year by changing their water use habits. The Washington Suburban Sanitary Commission has published a pamphlet suggesting water-saving habits concerned with toilet flushing, bathing and hygiene, laundry, dishwashing, drinking and cooking, and outdoor uses of water.[1]

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[1] Charles W. Howe and William J. Vaughan, "In-House Water Savings," Journal American Water Works Association (February 1972): 119.

[2] Consumer Reports, August 1969.

Water can be conserved with leak repair as well as with water-saving devices and changes in water use habits. Toilets and faucets are the major contributors to household leaks.[2]

A fourth method of reducing water usage is the reduction of water pressure coming into the house. This is especially useful if water pressure is greater than 4.2 kg/cm^2 (60 psi). Houston, Texas uses water pressure as a rationing device.[3] The water utility district does not guarantee a water pressure. When water demands become too great for the utility to supply, everyone's water pressure drops.

Dr. Joseph Harrington, Professor of Environmental Engineering at Harvard, has expressed concern that the reduction of water pressure will not only reduce water consumption but will also impair proper functioning of water-using appliances.[4] For example, washing machines which draw water for a certain time period rather than metering the amount of water they receive will not receive enough water to wash clothes adequately because water is flowing at a lower rate than the machine was designed for. Further research is needed to determine the tradeoffs between water savings and reduced appliance performance due to reduced water pressure.

New construction offers an excellent opportunity for water-saving. Houses and gardens can be designed with water conservation in mind. Water-saving toilets, showerheads, and other appliances can be installed at very little, if any, additional cost over non-water-saving devices. Plants indigenous to the area and requiring little water can be used in landscaping.

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[1] The Washington Suburban Sanitary Commission, A Customer Handbook on Water-Saving and Wastewater-Reduction.

[2] The Washington Suburban Sanitary Commission, Water-Saving and Wastewater-Reduction, 13.

[3] Telephone conversation with an engineer from the Department of Water Works, Houston, Texas, October, 1974.

[4] Dr. Joseph Harrington, personal communication.

3.3 Pricing and Metering

This literature review section describes (1) the criteria used in evaluating pricing methods, and (2) various pricing methods that are or could be used for charging water and sewer rates. (It should be noted that metering, is not among the pricing methods, since it is simply a way of measuring water consumption.)

3.3.1 Criteria for Evaluating Pricing Schemes

In the next section we will evaluate each of the candidate rate structures in terms of a number of criteria which we have developed on the basis of the literature review. To prepare for that analysis, we outline each of the criteria, and briefly explain its significance and applicability in this section. The criteria are (1) revenue adequacy, (2) water conservation implications, (3) administrative simplicity, (4) non-discriminatory distributive effects and (5) economic efficiency. Each of these will be discussed in turn.

Our first criterion "revenue adequacy" is not meant to indicate simply whether costs are greater than revenues. The relationship between total (or average) costs and revenues is, in any case, more a function of the level of rates than of the rate structure -- and yet it is the latter which we seek to evaluate here. However, in the real world of imperfect bureaucratic and political arrangements, it does matter whether or not revenues expand when use and hence costs rise. For if any and all revenue increases require positive administrative action, the possibility of shortfalls and fiscal unsolvency is increased. In a sense then, "revenue adequacy" is a part of "administrative simplicity", and is used here simply to mean a rate structure for which income grows automatically as use expands.

The second criterion, "water conservation implications" also requires some justification. From the viewpoint of economic efficiency, there is no reason to encourage conservation as a distinct goal. Instead, one simply wants all goods to have the "right" prices so that rational customers will balance the value, to them, of additional use against the cost of such consumption. However, as we discuss shortly, determining the "right" prices is extremely difficult in an imperfect world. Thus, given the explicit focus of this study, it is not unreasonable to single out the convervation implications of alternative strategies for special consideration.

Third, we propose to evaluate rate structures in terms of "administrative simplicity" -- that is, in terms of the technical difficulties and costs of implementing and operating them.[1] Thus, for example, a rate structure that looked attractive from the viewpoint of economic efficiency might not be desirable in practice because the savings it induced by giving consumers more accurate incentives might not be great enough to justify the costs of the whole system of monitoring and collection.

As a fourth basis for evaluating rate structures, we propose to consider whether or not the distributive implications of each rate structure are discriminatory by examining whether payments for service are proportional to the amount of (and the cost of) the service received. Thus, here we are not looking at "income distribution" in the economist's sense -- that is, at the relative impact of a program on the rich and the poor. Rather, we are concerned with "discrimination" in the legal sense, as embodies, for example, in the Robinson-Patman Act.

Our final criterion is "economic efficiency." Describing how we propose to analyze this characteristic requires some discussion since a sophisticated analysis is somewhat more complex than some treatments in the literature appear to recognize.

Simplifies models of production and consumption decisions imply that the economy will reach an "efficient" outcome when all markets are perfectly competitive and all prices are set equal to marginal social costs -- that is, equal to the costs of producing the last unit of output. In other words, all prices must reflect not only ordinary private costs, but also any external costs (like the costs of pollution), even if these are not reflected in market transactions. If this is done, the overall economic outcome will be "efficient" in the sense that the society could not have more of any one output without having less of something else -- thus there would be no wasted or misused productive capacity in the system.[1] Furthermore, the allocation of goods among individuals would be efficient in the sense that all mutually beneficial trades would occur. Hence, there would be no way to redistribute the goods produced so as to make any individual better off without also making someone else less well off.

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[1] J.A. Johnson, "Economic Analysis of Sewer Service Charge Formulas," Land Economics (February 1971): 81.

However, there are several reasons why marginal cost pricing in actual situations is not necessarily desirable. First, the prices of all goods in society in general are not set at marginal cost. Given this condition it is not necessarily true that the price of any particular product that is the object of public policy should be set at marginal cost. This is the so-called "second best" problem.[2]

For example, assume all prices except two are set at marginal cost. One of the remaining two is set by a monopolist above marginal cost and the other is to be set by a regulating body. Suppose further that the two goods are close substitutes and their consumption does not affect the consumption of other goods. What price should the regulating body set? If some prices are not set equal to marginal costs, it is not clear that others should be. As Mansfield puts it: "[If] some of the conditions for efficiency remain unfulfilled, there is no assurance that the reduction in the number of unfulfilled conditions will result in increased welfare."[1]

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[1] Steve H. Hanke, "Pricing Urban Water," in Public Prices for Public Products, ed. S.J. Mushkin, (Washington, D.C.: Urban Institute, 1972): 283-306; Steve H. Hanke and Robert K. Davis, "Demand Management through Responsive Pricing," JAWWA (September 1971); Jerome W. Milliman, "Price Policy and Land Value Taxation for Urban Water Supplies," The American Journal of Economics and Sociology (October 1960); Jack Hirshleifer, et al., Water Supply: Economics, Technology and Policy (Chicago: The University of Chicago Press, 1970):40-41. See also Chapter 5 below.

[2] Paul Anthony Samuelson, Foundations of Economic Analysis (New York: Atheneum 1974): 275; R.G. Lipsey and R.K. Lancaster, "The General Theory of the Second Best," Review of Economic Studies, 28.

It may well be better for the regulatory authority to also set the price it controls above marginal cost -- so that the ratio of the prices between the two substitutes accurately reflects the ratio of their marginal costs if, as we have assumed, the relationship between those two prices and all other prices will have relatively little impact on consumer choices. The fact that both goods have prices that are "too high" may have less distorting effect on economic efficiency than having one high and the other lower. In the first situation at least, consumers will make accurate choices between the two substitutes.[2]

A reverse argument can be made about goods which are complements (like coffee and cream) where an increase in the consumption of one tends to lead to an increase of consumption of the other. If one good of such a pair has a price that is above its marginal cost of production, it might pay to set the price of the other good below its marginal social cost so that the errors cancel out and the overall price for the two goods taken together more closely approximates the marginal social cost of the combined package.

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[1] Edwin Mansfield, Microeconomics -- Theory and Applications (New York: W.W.Norton and Company, Inc.),437

[2] M.J. Farrell, "In Defense of Public Utility Price Theory," Oxford Economic Papers, NS Vol. 10 (1958); E.J. Mishan, "Second Thoughts on Second Best," Oxford Economic Papers (1961); I.M.D. Little, The Price of Fuel (Oxford University Press, 1953); R. Rees, "Second Best Rules for Public Enterprise Pricing," Economica (August 1963); W.J. Baumol and D.F. Bradford, "Optimal Departures from Marginal Cost Pricing," American Economic Review, Vol LX, No 3 (June 1970).

A second reason for departing from marginal cost pricing has to do with income distribution in the strict sense, that is, the effect of prices on the relative well-being of various groups in the population. If the mechanisms for redistributing income in the society are imperfect, there might be some argument for keeping down the prices of those commodities on which lower income households spend a large share of their income, and on which they spend a larger share than relatively upper income spending units.[1] Of course the distributive "gain" might not be worth the efficiency "cost" in any particular instance. But that is a matter which must be considered in light of the facts of each case as it arises.

At a less fundamental level, perhaps, in addition to being occasionally undesirable, marginal cost pricing is not always easy to implement because it is difficult to find real world counterparts for the simple concepts and models on which the argument is based.

Because technology is constantly changing, it may be quite difficult to know exactly what marginal costs will be in a facility which is planned but not yet operating.[2] At exactly what point in the introduction of a new technology do we consider it sufficiently "proven" to use it as the basis for such calculations?

Similarly, there is a problem about the difference between short- and long-run marginal costs. If we set prices equal to whatever marginal costs might be in the short run with existing productive capacity, then prices might well tend to vary considerably over time as new facilities are brought into use and we move successively through periods of shortage (high marginal costs) and surplus (low marginal costs). On the other hand, if we try to use long-run marginal costs then we will make mistakes about short-run production decisions. It is worth noting that almost all the analysis in support of marginal cost pricing has been based on short-run, once-and-for-all equilibrium analysis. The kinds of evolutionary, dynamic considerations being raised here have been quite generally ignored.

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[1] E. Puzner, "Income Distribution and the Pricing of Regulated Outputs," in R.E. Caves and M.J. Roberts, eds., Regulating the Product (Ballinger, 1975).

[2] Z. Griliches , "Comment" in The Rate and Direction of Inventive Activity (Princeton University Press).

Furthermore, until physical facilities are fully utilized at peak demand, the marginal costs of all additional water supply (including peak periods) are really just variable costs, such as power, labor, chemicals, etc. Once the existing facilities are fully utilized, however, demands at peak periods imply added expense since new investments must be undertaken to meet such loads although correctly formulating such prices is very difficult.[1] In a situation in which there are economies of scale in construction, it pays to build somewhat ahead of demand, since lower costs result even with some surplus capacity in the short run.[2] Yet in such cases where long-run marginal costs are declining, setting prices equal to marginal costs will result in revenue less than costs, and the need for some subsidy scheme if the system is to be kept operating.[3] Note also that marginal cost pricing would imply setting different rates for customers whose service costs differ, e.g., those whose water came longer distances should pay higher prices.

An added argument against taking the case for marginal cost pricing too literally is that real consumers make imperfect choices so that even "the right" prices might not lead to optimal outcomes. [N.B. Some imperfection in choices is only rational in the global sense.][4] Consumers know that shopping time is valuable: it may not be worth their time to search all over town for the cheapest aspirin. However, consumers are also irrational in an economic sense. They may buy on a whim, or because their mother always did, or for some other non-economic reason. But whether consumers' choices are rationally or irrationally imperfect, the implication is the same: marginal cost prices will not necessarily lead to the best possible outcome.

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[1] S.H. Hanke, "Pricing Urban Water," in S.J. Mushkin, ed., Public Prices for Public Products, (Urban Institute, 1972); P.O. Steiner, "Peak Load and Efficient Pricing," Quarterly Journal of Economics, (November 1957); O.E. Williamson, "Peak Load Pricing and Optimal Capacity Under Indivisibility Constraints," American Economic Review (September 1966).

[2] J.Chi, "Wastewater Conveyance Models," in R. Dorfman, et al., ed., Models for Managing Regional Water Quality, (Harvard University Press, 1972).

[3] J. Hirshleifer, J.C. DeHaven, and J. Milliman, Water Supply, (University of Chicago Press, 1970).

[4] H. Simon, "A Behavioral Model of Rational Choice," Quarterly Journal of Economics, 1955.

Finally, note that the rule, "prices should equal marginal social cost," is not adequate as a complete guide for policy choices. It claims to distinguish "right" from "wrong" situations, but does not give us guidance as to how to compare a number of options all of which are imperfect, for example, if there are two prices neither of which is equal to marginal costs. Is there any way in which we can say that one is to be preferred to the other, that one scheme leads to a more efficient outcome than the other?

As a way of resolving all these problems, our literature review suggests accepting the "price equal to marginal costs" criterion as a measure of relative economic efficiency in this case, despite the arguments against it which we have reviewed. The proposed criterion utilizes a comparison of the sum of the consumer surplus and producer surpluses[1] generated by each alternative, i.e., the willingness of consumers to pay for an outcome minus the costs. Graphically the measure is the area between the marginal cost and the demand curves. This measure has the advantage of being relatively easy to develop empirically, even though the estimation of demand functions is by no means a simple task. The marginal cost pricing rule is implicit in this criterion, in the sense that the sum of producers' and consumers' surpluses will be maximized when prices are equal to marginal costs.

Given all the objections noted previously it might be thought difficult to defend such a criterion. Although such a criterion will not necessarily be valid, in this particular case the major difficulties with marginal cost pricing are less serious problems than they might well be in other circumstances.

First, in terms of resource allocation, residential water use does not resemble a commodity whose consumption is strongly dependent on the prices of particular substitutes or complements. Hence the "second best" arguments discussed above would not seem to imply any strong reason for making prices depart from marginal costs in this particular instance. Insofar as there is any argument to be made in this regard, it would appear to imply that water prices, if anything, should be above marginal costs, given the presence in the economy of many imperfect markets which do tend to produce such outcomes.

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[1] Robert Lee Greene, Welfare Economics and Peak Load Pricing (Gainesville: University of Florida Press, 1970), 20.

Secondly, from an income distribution viewpoint, manipulating the price of water does not appear to be a particularly effective way of altering the distribution of well-being in the society in a more equitable direction. After all, many large residential water consumers are relatively well-to-do lawn waterers who would not seem especially deserving of a special subsidy in the form of low water prices. Indeed, given regional variations in climate, residential patterns and water use, trying to use water prices to achieve distributional objectives would seem likely to generate its own inequities among those in differing geographic areas.[1]

Moving on to other objections, there is the practical problem of computing marginal costs, in light of changing technology and discontinuous dynamic adjustments in physical facilities? The first problem is relatively less serious in the water supply area than it might be in some other cases simply because it is a sector in which technology is not in a state of rapid flux. Nonetheless,as Turvey has suggested,[2] the correct way to solve such problems is to ask what decisions about supply are being guided by the analysis, and hence what costs in fact, will be incurred on the margin. On the basis of such logic, and because this is an exploratory and abstract study, we will ignore such complexities as the varying impact on cost of variations in the shape of the load curve of marginal demands, and instead simply hypothesize various plausible possible patterns for the long-run marginal cost schedule -- recognizing that these would have to be developed with some judgement and finesse in any real world application.

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[1] Of course it is possible to take distributional issues into account in other ways, for example, by giving different weights to the "willingness-to-pay" expressed by members of different income or regional catagories in the population. Such refinements, however, would not noticeably change the analysis which follows. On the use of such techniques see S.A. Marglin, Public Investment Criteria, (MIT Press, 1969).

[2] R. Turvey, Optimal Pricing and Investment in Electricity Supply (MIT Press, 1969).

Finally, the imperfection of actual consumer choices and the need for a criteria that reflects incremental changes come together in helping to justify the proposed approach. That is, we are only using the sum of consumer and producer surplus as an index of relative economic efficiency -- a step which clearly involves making a series of imperfect simplifying assumptions. Since no claim is made that this choice criterion will infallibly lead to an "optimal" outcome, imperfections in consumer rationality are not really critical objections to the method. Instead such irrational behavior is reflected by the fact that the revealed demand curve may not accurately capture the well-considered willingness-to-pay of the buyers in question. But especially given large numbers, and the possibility of errors by individuals cancelling each other out, this does not seem to be an objection serious enough to warrant abandoning the approach.

In summary, we propose to evaluate pricing schemes by all of the various criteria discussed in this section. We recognize that none of the measures are perfect. Indeed, some are highly qualitative and judgmental. Nevertheless, taken together, and used with care, they would appear to constitute a reasonable basis on which to evaluate alternative water pricing structures.

3.3.2 Evaluation of Pricing Schemes

To begin our evaluation of pricing schemes, consider first the flat rate -- a system in which each customer pays a fixed charge regardless of use. A flat rate does not require metering, and for just that reason the bill does not relate payments to water use. Flat rates may be based upon the class of consumer, number and/or size of water connections, the number and type of appliances, or some other determinants such as house value.[1] Flat rates are not considered revenue adequate because they provide no automatic mechanism for increasing revenue as costs, caused by increased demand, increase. They are also ineffective in achieving water conservation because they offer no incentive to avoid waste, repair leaks or otherwise reduce consumption.[1] The flat rate structure is the simplest of the pricing methods to administer. Whether the rate structure is discriminatory depends upon how well the scheme discriminates between classes of customers who, in fact, impose different costs on the system. In general, such policies are not economically efficient because the price does not reflect the marginal cost of supplying water and treatment services.[2] However, the cost of metering and billing may be sufficiently large in some cases as to make flat rates an attractive choice overall because the gains from flow-based pricing are not always worth the costs of achieving them.

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[1] J.A. Johnson, "Economic Analysis of Sewer Service Charge Formulas," Land Economics (February 1971): 83.

A decreasing block rate is a rate which is based upon the quantity of water used: as the quantity increases the rate for added consumption declines in a series of "steps" or "blocks." Decreasing block rates are potentially revenue adequate because the revenue received is directly related to the amount of water supplied, although, of course, whether the revenue will cover costs depends upon whether the consumer who increases his demand is charged an incremental rate high enough to cover the incremental costs his expanded use imposes on the system. In terms of water conservation, decreasing block rates encourage water use because marginal consumption confronts successively lower costs compared to a system such as increasing block rates (assuming that both generated similar amounts of revenue at a given output).

From an efficiency viewpoint, it is difficult to evaluate such a scheme since, of course, the relationship of marginal costs to prices will depend on the level as well as on the structure of rates. We do know, of course, that such schemes take no account of peak load problems, and furthermore, it is not at all clear that the short-run marginal social costs of supplying any particular user really do decline -- as this structure seems to assume. Hence overall, declining block rates are not notable attractive from an efficiency viewpoint.

The second rate scheme to be considered, constant unit prices, involves charges based directly on the amount of water used. As long as the long-run average costs of new water supplies (i.e., the costs of new capital investments) are not rising, this pricing system too can be revenue adequate since revenues increase as cost increases. Constant unit prices also do somewhat promote water conservation because people must pay for what they use, although, as in all schemes, the magnitude of water conservation will depend upon the price elasticity of demand for water. In terms of administrative simplicity, metering is required (as in all schemes but the simplest). On the other hand, in terms of discrimination, while constant unit prices might at first seem acceptable because all consumers are charged prices proportional to use, if one consumer is more expensive to service than others, he is in effect being subsidized. Like declining block rates, such a scheme can be efficient as long as the price is set equal to marginal social costs. However, there is an element of inefficiency in such schemes simply because rates do tend to be uniform among customers as well as for each purchaser. As a result, variations in costs due to location or use remain unreflected in prices.

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[1] Hirshleifer, Water Supply, 1970, 44.

[2] Hirshleifer, Water Supply, 1970, 44.

An increasing block rate is also based on the quantity of water used, but the charge per unit of water increases with volume. This rate structure is revenue adequate and it promotes water conservation since large users are penalized. In terms of administrative simplicity the increasing block rate structure is equivalent to the decreasing block rate structure.

From the viewpoint of discrimination, while average payments will vary with the size of the customer purchases (as with declining block rates), whether that is discriminatory or not depends as well on the manner in which average costs change with use. In terms of efficiency, increasing block rates are appropriate where average costs increase with output. In such cases, if constant unit cost pricing is employed to achieve efficiency, the utility might earn more profit than is legal. Increasing block rates could achieve the efficiency results of marginal cost prices, without the excess profits. Also, increasing block rates can be structured in a fashion to insure that they serve as seasonal prices, with the consumer facing higher prices in the peak seasons.[1] Again, of course, the level of rates as well as the rate structure are crucial from this perspective.

Seasonal rate structures charge more during the summer months than during winter months. These rate schemes are water conserving[2] since they discourage use during the summer months when demand is high and the system is strained (see Figure 3-4). They are more complicated to administer than a nonseasonal rate, but not overly difficult and they are revenue adequate and efficient,[1] in that a higher rate is charged for more expensive water. (Summer water is more expensive because it increases capacity requirements.) They have favorable distribution effects because those who use water that is more expensive to provide are charged a higher rate.

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[1] Jerome Milliman, "Policy Horizons for Future Urban Water Supply, "Land Economics, 39 (May 1963):109-132.

[2] Steve H. Hanke & Robert K. Davis, "Demand Management Through Responsive Princing," JAWWA (September 1971: 560.

Rates based upon hourly peaks[2] are also revenue adequate, water conserving, and have favorable distributional effects. They are potentially the most efficient since they could be set to most closely approximate marginal social costs in varying circumstances. However, these rates are difficult to administer because an economically feasible meter capable of handling such a pricing scheme has not been developed. Telemetered meters have been developed and are possibilities for the future; however, they are currently too expensive to be practical. Seasonal rates may be more effective in reducing water consumption than hourly rates because peak prices may be avoided by shifting consumption in time.[3]

Spatial rates increase as the distance from the utility to the consumer increases.[4] This structure discourages urban sprawl and promotes water conservation since suburban dwellers consume more water for price elastic outdoor uses (such as lawns and swimming pools) than urban dwellers. It is revenue adequate, has favorable distribution effects and is efficient. On the other hand, administrative complexity is increased.

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[1] Hirshleifer, *Water Supply*, 1970, 46.

[2] Hanke, "Demand Management", 556.

[3] Robert L. Greene, "Peak Load Pricing: An Application," *Quarterly Review of Economics and Business* 9, (Autumn 1973): 106.

[4] Jerome W. Milliman, "Price Policy and Land Value Taxation for Urban Water Supplies," *The American Journal of Economics and Sociology* (October 1960).

Table 3-3 displays the ranking of various water rate schemes with respect to revenue adequacy, water conservation, administrative simplicity, distribution effects, and efficiency. Based on the results of the literature review, each of the pricing schemes is rated good, fair, or poor for each criterion. Rate structures will be further examined by the computer model described in Chapter Five.

TABLE 3-3

RANKING OF PRICING SCHEMES
BASED ON LITERATURE REVIEW RESULTS

	Revenue Adequacy	Water Conservation	Administrative Simplicity	Distribution Effects	Efficiency
Flat Rate	poor	poor	good	poor	poor
Decreasing Block Rate	fair	poor	fair	fair	fair
Constant Unit Price	good	fair	fair	fair	good
Increasing Block Rate	fair	good	fair	fair	good
Seasonal Rates	good	good	fair	good	good
Hourly Peak Rates	good	good	poor	good	good

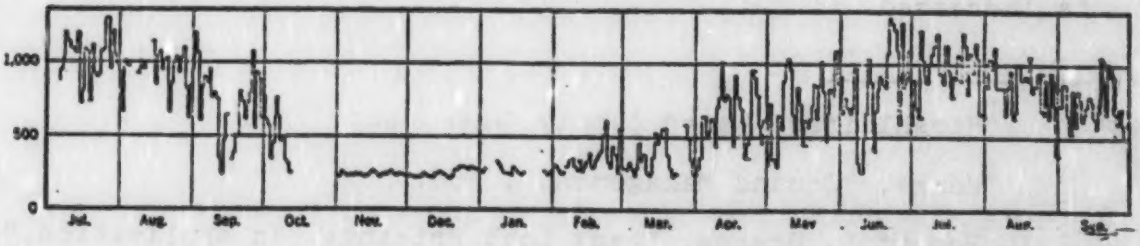

Figure 3-4 Example of seasonal pattern of daily water use: Creekside Acres, East Bay Municipal Utility District, California. (F.P. Linaweaver, Jr., John C. Geyer, and Jerome B. Wolff, "Summary Report on the Residential Water Use Research Project," JAWWA (March 1967): 270. Reprinted from Journal of American Water Works by permission of the Association. Copyrighted 1967 by the American Water Works Association, Inc., 2 Park Avenue, New York, N.Y., 10016.)

3.4 Public Acceptance

Any plan to reduce wastewater flow from households depends on public opinion both for its initial adoption and for its ultimate success. The four ways of encouraging water saving are: (1) public education to encourage voluntary conservation, (2) installation of water-saving devices, (3) pricing schemes to discourage water use, and (4) reuse of treated wastewater. This section of the report examines each of these methods separately in terms of their public acceptability.

3.4.1 Public Education

Public education is one way of reducing domestic water consumption, through increasing public awareness of the reasons for using less water and of the means of doing so. When the Washington Suburban Sanitary Commission (WSSC) started bringing the problem of water consumption to public attention they found the response to be quite good.[1] People thought of methods of saving water and were eager to use water-saving devices. This example is similar to other experiences that show consumer acceptance during water shortages.[2] When the public perceives the problem of maintaining an adequate water supply, it seems they are willing to follow advice as to how to conserve water. But they must first be convinced that there is a problem. The WSSC presented the problem from the vantage point of waste treatment rather than the vantage point of water supply.

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[1] The Washington Suburban Sanitary Commission, Final and Comprehensive Report: Washington Suburban Sanitary Commission's Water Conservation/Wastewater Reduction Customer Education and Behavioral Change Program (Washington, D.C.: The Washington Suburban Sanitary Commission, 1974).

[2] H.E. Abbott, H.G. Cook, and R.B. Sleight, Social Aspects of Urban Water Conservation (Arlington, Virginia: Century Research Corporation, 1972).

They told their consumers that treatment plants were overloaded. Public education as to methods of water conservation can be achieved through television, radio, newspapers and schools. These media should familiarize the public with all of the methods presented in Section 3.2. Another method of public education is the adoption of a labeling program: water-using appliances would be required to bear a label stating how much water they use, and consumers could then consider the water requirements of appliances in their purchase decisions.[1]

3.4.2 Water-Saving Devices

Public acceptance of water-saving devices is presented in Table 3-4. This table shows the results of a survey of 387 homeowners conducted by General Dynamics. The survey was conducted nationwide so that climatic or cultural variations could be recognized. No major differences were detected.[2] Survey results indicate the strong acceptability of reduced flush toilets, water-saving showerheads, and some water reuse schemes. On the other hand, a majority surveyed were opposed to more radical changes such as home urinals. Public acceptance of water-saving devices is further enhanced if they are attractive, convenient and economical.

3.4.3 Pricing Schemes

It is generally felt that a major factor encouraging the use of water in American households is the low price. There seems to be agreement among many water commissioners that higher prices should be charged for water, to cover expenses, reduce wastefulness, and make the consumer aware that water is limited in quantity. John Sears Commissioner

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[1] Letter from David Mair, Water Commissioner, Columbus, Ohio, October 17, 1974.

[2] James R. Bailey, A Study of Flow Reduction and Treatment of Waste From Households, General Dynamics (December 1969), 108.

TABLE 3-4

SUMMARY OF SURVEY RESULTS

WATER-SAVING DEVICE OR TECHNIQUE	PERCENTAGE OF RESPONSES WHICH INDICATE ACCEPTANCE FOR THE USE OF THESE TECHNIQUES OR DEVICES		
	Home Owners (387)*	Plumbing Contractors (40)	Architect Engineers (30)
Reduced flush toilets	92	49	79
Water-saving faucets or showerheads	87	87	90
Reuse of wash waters for:			
A. Toilet flushing	82		86
B. Lawn irrigation	82		86
Dual cycle toilets	79	56	90
Toilets that disinfect and reuse flush water	46	21	68
Home urinals	37	24	77

* The number of questionnaires returned.

(J. Bailey and H. Wallman, "Flow Reduction of Wastewater from Households," Water and Sewage Works (March 1971): 70.)

of the Boston Metropolitan District Commission, said at the June 1974 American Water Works Association (AWWA) convention, "Nobody respects a commodity which is all but given away. I feel that we should move toward a price structure which encourages respect for this resource."[1] Looking back at the 1956 AWWA convention, John H. Murdoch claimed that "the consumer has been educated by water works management to consider water 'cheap as dirt' and the result of that education is an instinctive, passionate public resistance to secure funds for fully adequate service."[2]

David Mair, Water Commissioner of Columbus, Ohio, points out that water and sewer rate increases are unpopular; this is attributable in part to bitterness about inflation.[3]

3.4.4 Water Recycling

Due to the need for further study, and the controversy already present concerning water quality, the introduction of recycled water - such as reclaimed wastewater - is not an immediate possibility for drinking and cooking water. Public reaction to reuse of wastewater and public attitudes toward the possibility of various types of water reuse are discussed below.

An article by D. F. Metzler[4] deals with reaction to the domestic use of recycled sewage water during a severe drought. Treated sewage was "recirculated through a stabilization pond, the water treatment plant and the water distribution system . . . Initial public acceptance was good, probably because the citizens knew that their supply normally received diluted treated sewage from seven upstream communities . . . Public reaction became more adverse when stories appeared in local newspapers. Bottled water sales flourished . . ." Although local physicians agreed that the tap water was safe, "there was a general tendency to blame almost any kind of sickness - particularly stomach or intestinal disorders - on the water."[1] In the Chanute case, consumer acceptance of treated sewage was poor probably because the safety of the water was a controversial matter.

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[1] John W. Sears, Statement at AWWA Convention (Hynes Memorial Auditorium, Boston, Mass., 20 June 1974).

[2] John H. Murdoch, Jr., "Seventy-five years of Too Cheap Water," Journal American Water Works Association (August 1956).

[3] Letter from David Mair, Water Commissioner, Columbus, Ohio, 17 October 1974.

[4] Dwight F. Metzler, et al., "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas," Journal American Water Works Association (August 1958).

William H. Bruvold examined "Public Attitudes Toward Reuse of Reclaimed Water" in a non-emergency, low-contact situation. He found that most were indifferent to the use of reclaimed wastewater on golf courses and parks. One hundred residents in each of the ten California communities studied, five with facilities supplied with reclaimed water and five without, were questioned about their knowledge of and attitudes toward reclaimed water. Very few were opposed to low-contact use, such as for lawn irrigation. More were opposed to higher-contact uses. A high 56.4 percent were opposed to use for drinking water, 54.5 percent for food preparation, 38.75 percent for bathing, 22.8 percent for laundry and 3.8 percent for toilet flushing. Bruvold found that although there was some association between the presence and use of a reclamation facility and public attitudes, it could not be concluded that "the use of existing reclamation facilities would have a powerful effect on attitude."[2]

A 1973 Gallup poll presents similar findings, with 54.5 percent of the population objecting to drinking recycled sewage, 38.2 percent not objecting, and 7.3 percent holding no opinion.[3] As in Bruvold's survey, the lower the respondent's level of education the more likely he was to object. The Gallup poll also found that older respondents were more likely to object, with a majority aged 30 and over objecting and a minority under 30 objecting.

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[1] D.F. Metzler, "Emergency Use of Reclaimed Water."

[2] William H. Bruvold, Public Attitudes Toward Reuse of Reclaimed Water (University of California Water Resources Center Contribution No. 137, August 1972).

[3] Gallup Poll, "Water Quality and Public Opinion," Journal American Water Works Association (August 1973).

Bruvold believes that since a majority of the public is not ready for it, the introduction of high-contact use of reclaimed water would meet opposition great enough to damage the environmental movement. He also concludes that the changing of public attitudes by providing scientific information about purification methods is more important than convincing the public of the need for water. Burvold recommends treatment plant tours and low-contact but highly visible use of reclaimed water acceptable to the public, combined with education programs stressing the cleanliness of recycled water.[1]

3.4.5 Summary and Conclusions

Four methods of encouraging water saving have been examined in terms of their public acceptability. It was found that the public responds favorably to public education and the concept of installing water-saving devices. However, the public opposes price increases and high-contact use of treated wastewater.

3.5 Infiltration and Inflow

Infiltration is defined as the difference between maximum sewage flow in dry weather and maximum flow attributable to sanitary sewage. Inflow is the difference between dry weather flow and wet weather flow. Infiltration and inflow are of interest in this report because they represent a large fraction of the water reaching waste treatment plants. The American Public Works Association maintains that average infiltration rates represent as much as 15 percent of the total flow, while peak rates can be as high as 30 percent.[3] O. John Schmidt maintains that wet weather flow is two to six times as great as dry weather flow.[1] Table 3-5 further illustrates this point.

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[1] Bruvold, Public Attitudes.

[2] Environmental Protection Agency, Sewer System Evaluation (Washington, D.C.: EPA, 1974), 3.

[3] American Public Works Association, Control of Infiltration and Inflow into Sewer Systems (1970).

The experience of the WSSC in the Cabin John Drainage Basin is also of interest to this report. Despite the fact that water savings were achieved through the implementation of various water-saving methods in 1972, no reduction of sewage flows was discernible, although where devices were properly installed, water use was reduced. Infiltration was held responsible for masking the results of water use reduction.[2]

In conclusion, infiltration and inflow are major contributors to wastewater flow. Household water conservation with devices must be considered in relation to the real need to conserve and to other ways for reducing water use and sewage flows. A reduction of infiltration and inflow might be more beneficial to wastewater treatment plants than the installation of water-saving devices. However, water-saving devices are effective in reducing potable water demand.

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[1] O. John Schmidt, "Pollution Control in Sewers," Pollution Control Federation 44, (July 1972).

[2] The Washington Suburban Sanitary Commission, Final and Comprehensive Report: Cabin John Drainage Basin Water-Saving Consumer Education and Appliance Test Program (Washington, D.C.: The Washington Suburban Sanitary Commission, 1973), 4.

TABLE 3-5

DRY- AND WET-SEASON FLOWS IN SEPARATE SANITARY SEWERS†

Location	Year	Population	Dry-Weather Flow million liters/ day	Wet-Weather Flow million liters/ day	% Increase of Wet With Respect to Dry Weather Flow§
Duluth, Minn.	1967	110,000	42.8	113.5	165
Denver, Colo.	1956	510,000	151.4*	216.0*	43
Grand Island, Nebr.	1962	25,000	14.8	25.4	72
Leavenworth, Kans.	1967	41,000	18.9*	37.9*	100
Bay City, Mich.	1967	60,000	60.5	265.0	338
Dallas, Texas	1960	715,500	442.9	855.0	93
Mission Township, Main Sewer District No. 1 Johnson Co., Kans.	1969	50,000	66.2	394.0	495
Holland, Mich.	1969	19,300	16.3	19.8	21
Austin, Texas	1966	270,000	73.5*	176.0	139
Hays, Kansas	1965	15,600	9.5	17.8	87
Paragould, Ark.	1962	7,700	4.2	22.7	440
Osawatomie, Kans.	1966	4,700	4.5	11.0	144
Sheridan, Wyo.	1960	11,500	16.3	64.3	294
Billings, Mont.	1960	50,500	40.8	66.9	64
Billings, Mont.	1968	59,500	39.7	53.0	33

† All flows cited are peak; those marked * are average.

§ The increase of sewage flow in wet-weather over dry-weather flow is a partial indication of the amount of infiltration and inflow occurring.

(O. John Schmidt, "Pollution Control in Sewers," Journal Water Pollution Control Federation, 44, July 1972: 1385)

CHAPTER FOUR

LEGAL CONSTRAINTS ON OPTIONS CONSIDERED

4.1 Introduction

This chapter is devoted to examining the legal and institutional problems involved in implementing household flow reduction options suggested in this report (water-saving devices, metering, and the water-recycled toilet).

To investigate the legal and institutional constraints of installing water-saving devices in the home, building and plumbing codes were gathered from selected areas of the country. Building codes are less specific than plumbing codes on the subject of water-saving devices; however, they are important simply because they stipulate that plumbing codes must be followed.

The legal constraints on implementing water metering or user service charge schemes involve legislative control, restrictions on utility revenue use, and enforcement. The core problem is whether rate increases will be allowed and implemented through the state or the municipality. Some sewage authorities have ordinances that conflict with the pricing schemes that might be considered desirable in terms of economic welfare.

The water-recycled toilet is treated separately due to special considerations. The main problem with the water-recycled toilet is the possibility of cross-connections. Sanitary problems must also be taken into account.

4.2 Water-Saving Devices

One way of reducing wastewater flow is the installation of water-saving devices in the home. This option is related to metering, pricing, and user service charges, because higher prices for water will provide an incentive for consumers to install water-saving devices. Therefore, there are two approaches to the legal constraints involved with adopting this option: (1) encouraging voluntary installation of water-saving devices, or (2) requiring the installation of water-saving devices in all buildings, or in new buildings alone, by law.

The encouragement of voluntary installation would be promoted through the manipulation of metering, pricing and user service charge schemes. Consumers would voluntarily install water-saving devices in response to economic incentives.

The second approach involves an examination of the legal and institutional constraints on the mandatory installation of water-saving devices. The constraints vary with the scope of the requirements. Requirements which apply to new and renovated buildings are more easily instituted than requirements which call for changes in existing buildings.

4.2.1 Methodology

The methodology used to evaluate the legal and institutional constraints on installing water-saving devices involved research into selected building and plumbing codes. The United States was divided into four main regions: East, West, Midwest, and South, in order to evaluate different water supplies and needs based on geography and topography.

4.2.2 Building Codes

There are four main building codes which serve as models for state statutes. These codes are the Uniform Building Code,[1] the Southern Standard Building Code[2], the

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[1] Uniform Bldg. Code (1970)

[2] Southern Standard Bldg. Code (1971)

BOCA Basic Building Code,[1] and the National Code.[2] Building codes are relevant to the discussion because they usually provide clauses that incorporate state plumbing codes.

An example of such a clause is in the N.Y. Bldg. Code, "General Requirements: Plumbing and gas piping shall be designed and installed so as to satisfy the following conditions and requirements of reference standard RS-16 [which is the plumbing code]."[3] Two more examples from the N. Y. Bldg. Code are the following clauses, the first consistent with the purposes of water-saving devices and the second possibly restricting the installation of water-saving devices. The first is the N. Y. Bldg. Code "Water Conservation: Plumbing shall be designed and adjusted to use the minimum quantity of water consistent with proper performance and cleansing of the fixture or plumbing appurtenance."[4] The second is the N. Y. Bldg. Code "Use of Nonconformity Material or Equipment: No person shall use or install any new or used plumbing material or equipment, unless it complies with the requirements set forth in this article and reference standard RS-16."[5]

The states of Pennsylvania, Virginia, New Jersey, Connecticut, Rhode Island, Oklahoma, Michigan and Missouri have adopted the BOCA code. The Massachusetts State Building Code is modeled after the BOCA Basic Building Code for 1970.[6] Massachusetts State Building Code Article 17 on plumbing, drainage, and gas piping states that "Chapter 142, Section 2 of the Massachusetts General Laws Annotated as Amended, provides that all construction, alteration, repair, and inspection of plumbing shall be in conformance with the

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[1] Building Officials Code Administration Basic Building Code (1971).

[2] National Bldg. Code (1971).

[3] N. Y. Bldg. Code §§ 1600 Gen., C 26-1600.6 (1973).

[4] N. Y. Bldg. Code §§ 1600 Gen., C 26-1600 (c) (1973).

[5] N. Y. Bldg. Code §§ 1600 Gen., C 26-1600 (1973).

[6] Mass. State Bldg. Code (1974).

Commonwealth of Massachusetts Uniform State Plumbing Code promulgated by the Board of State Examiners of Plumbers of the Commonwealth of Massachusetts Department of Public Utilities."[1]

4.2.3 Plumbing Codes

Plumbing codes were examined covering a variety of cities and states. The National Plumbing Code Handbook interprets by illustration and explanatory remarks the American Standard National Plumbing Code, ASA A40.8-1955.[2] This code suggests the basic plumbing requirements meeting the minimum stipulations of most states. Other plumbing codes examined were the Massachusetts State Plumbing Code,[3] the Colorado State Plumbing Code,[4] the Wisconsin Plumbing Code,[5] the City of Atlanta Plumbing Code,[6] and the Plumbing Code of San Marino,[7] a small suburb of Los Angeles.

The first legal question raised in installing a water-saving device is whether it is permitted by the plumbing code. The National Plumbing Code stipulates in Section 2.5 Repairs and Alterations: "Existing Buildings: In existing buildings or premises in which plumbing installations are to be altered, repaired or renovated, deviations from the provisions of this code are permitted, provided such deviations are found to be necessary, conform to the intent of this code, and are approved in writing by the administrative authority."[8]

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[1] Mass. Ann. Laws Ch. 142, § 2 (1966).

[2] Manus, National Plumbing Code Handbook, New York (1971).

[3] Mass. Plumbing Code (1973).

[4] Colo. Plumbing Code (1972).

[5] Wis. Plumbing Code (1972).

[6] Atlanta, Ga. Plumbing Code (1972).

[7] San Marino Plumbing Code (1973).

[8] Manus, National Plumbing Code Handbook, § 7.8, New York (1971).

The most specific reference to water-saving devices in the National Plumbing Code Handbook is the clause on urinals, Section 7.8: "Automatic Flushing Tank: Tanks flushing more than one urinal shall be automatic in operation and of sufficient capacity to provide the necessary volume to flush and properly cleanse all urinals simultaneously. The objection to automatic flushing tanks is that the water usage is very high: Therefore automatic flushing tanks should be considered only where they will be used temporarily."[1]

The Colorado State Plumbing Code mentions that "The provisions of this code are not intended to prevent the use of methods, materials, and fixtures which, as a matter of fact, will meet reasonably safe standards of strength and sanitation."[2] However, most plumbing codes specify the minimum flow rate for fixtures.

For example, the Wisconsin Plumbing Code requires the rates shown in Table 4-1.[3] Massachusetts has slightly higher standards as shown in Table 4-2.

Some of the water-saving devices suggested in this report would violate these flow standards. Attention should be drawn to the shower fixture that would reduce flow to 3 gallons per minute, while the code requires 5gpm in Massachusetts.[4]

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[1] Manus, National Plumbing Code Handbook, § 7.8, New York

[2] Col. Plumbing Code § 3.1.2 (1972).

[3] Wis. Plumbing Code § H62.13 (1972).

[4] Mass. Plumbing Code § 14.3.1 (1973).

TABLE 4-1

MINIMUM FLOW RATES PER OUTLET

FIXTURE	FLOW RATE MINIMUM	
	liters/min	gpm
Lavatory	7.6	2
Sink	15.1	4
Bathtub	22.7	6
Laundry tray	18.9	5
Shower	11.4	3
Water closets		
Tank type	11.4	3
Blowout actions	Depends on flow pressure	
Jet action	Depends on flow pressure	
Drinking fountain	2.8	0.75
Wall hydrant	18.9	5

Source: Wisconsin State Plumbing Code

TABLE 4-2

MINIMUM FLOW PRESSURE AND FLOW RATES

LOCATION	FLOW PRESSURE		FLOW RATE	
	kg/cm^2	psi	liters/min	gpm
Ordinary basin faucet	0.56	8	7.6	2.0
Self-closing basin faucet	0.56	8	9.5	2.5
Sink faucet, 3/8 inch	0.56	8	17.0	4.5
Sink faucet, 1/2 inch	0.56	8	17.0	4.5
Bathtub faucet	0.56	8	22.7	6.0
Laundry tub cock, 1/2 inch	0.56	8	18.9	5.0
Shower	0.56	8	18.9	5.0
Ball-cock for closet	0.56	8	11.4	3.0
Flush valve for closet	1.05	15	58.1	15.35
Flushometer valve for urinal	1.05	15	56.8	15.0
Drinking fountains	1.05	15	2.8	0.75
Sill cock-wall hydrant	0.70	10	18.9	5.0

Source: Massachusetts State Plumbing Code

As another example the flow standards for the City of Atlanta in Table 4-3 require a shower flow of 4 gpm (15.1 liter per minute).[1] A sonsumer could in most cases reduce the flow of such a shower by using an aerator, but if a plumbing contractor permanently reduced the flow from all the showers in a building, he might be in violation of the code.

These codes illustrate the fact that legislation to require the use of water-saving devices would sometimes require changes in existing legislation. Many water-saving devices, however, shuch as aerators and water-saving washing machines, would not be in violation of the codes. In the cases of the dual cycle and water-saving toilets, building inspectors would have to be convinced that these new toilets have sufficient flushing capacity, since the National Plumbing Code Handbook specifies in Section 7.7 on Flushing Devices: Water closet tanks shall have a flushing capacity sufficient to properly flush the water closet bowls with which they are connected."[2] The Atlanta code is even more specific: "Water closet bowls shall be of the siphon-jet, reverse-trap, washdown, or blowout type with wall outlet. Water closet bowls and traps shall be made in one piece and shall be provided with an integral flushing rim constructed so as to flush the entire interior of the bowl."[3]

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[1] Atlanta, Ga. Plubing Code § P-1603.7 (1972).

[2] Manus, National Plumbing Code Handbook 37.7, New York (1971).

[3] Atlanta, Ga. Plumbing Code § P-1206.1 (1972).

TABLE 4-3

MINIMUM REQUIRED FLOW RATES AND PRESSURES

LOCATION	FLOW PRESSURE		FLOW RATE (at point of discharge)	
	Kg/cm^2	psi	liters/min	gpm
Ordinary basin faucet	0.56	8	7.6	2
Self-closing basin faucet	0.56	8	9.5	2.5
Sink faucet 3/8 inch	0.56	8	11.4	3
Sink faucet 1/2 inch	0.56	8	11.4	3
Bathtub faucet	0.56	8	15.1	4
Laundry tub cock 1/2 inch	0.56	8	15.1	4
Shower	0.56	8	15.1	4
Ball-cock for closet	0.56	8	11.4	3
Flush valve for closet*	1.05	15	56.8-132.5	15-35
Flushometer valve for urinal	1.05	15	56.8	15
Drinking foundation outlets	1.05	15	2.8	.75
Sill cock-wall hydrant	0.70	10	18.9	5
Flush valves for wall hung, blow-out and syphon-jet water closets	1.76	25	132.5	35

Source: City of Atlanta Plumbing Code

*Wide range due to variation in design and type of closet flush valves.

Another legal consideration relating to water-saving devices is whether or not homeowners themselves can carry out the installation. In general, it appears that they can. The National Plumbing Code Handbook specifies that "No plumbing work, unless excepted in this section, shall be undertaken prior to the issuance of a permit by the municipality. A permit shall be issued to a licensed master plumber except as provided in § 19.9." The section referred to states that "Provided the owner will abide by the plumbing code in every respect, this should be allowed."[1,2] In addition to obtaining a permit, the homeowner must in general also comply with all the rules and regulations pertaining to design and installation, including tests and inspection.

Plumbing codes are often very detailed. If a state implementation program required water-saving services in new or renovated homes, the plumbing codes would have to describe the device, materials and size according to number of fixtures or number of people, and provide a method for enforcement, such as building inspection.

4.2.4 Requiring Water-Saving Devices

The major legal question of requiring water-saving devices by code is a Fifth Amendment Due Process and "Taking" question. Codes requiring the installation of water-saving devices might be viewed by the courts as a taking of property and hence unconstitutional. Such mandatory statutes might also be viewed as a misuse of police power.

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[1] Manus , National Plumbing Code Handbook, § 19.9, New York (1971).

[2] Some codes have been invalidated because they prohibit the legal owner of a proposed home from installing his own plumbing or making alterations and additions to his own home.

A relevant question in considering mandatory codes is whether or not they are justified in cost-benefit terms. In some cases, as shown in Chapter 6, devices may be cost-effective for replacement of non-functioning units or for new installations, but not for replacement of functioning units. In such cases, a requirement for across-the-board installation is likely to be challenged. However, the Washington Suburban Sanitary Commission has successfully adopted plumbing codes that mandate, for example, 3 1/2 gallon toilets and reduced-flow showers in new development installations and for replacement.[1]

4.2.5. Summary

Legal constraints vary with the jurisdiction, and the particular code system. The lack of uniformity hampers state-wide legislative changes. Even in a single municipality, mandatory codes may encounter legal difficulties. A relevant consideration in framing such codes is whether or not a device is justified in cost-benefit terms for across-the-board installation or only in new installation and renovation.

In any event, it would appear desirable to revise codes to permit the use of water-saving devices where this is warranted on the basis of economic, sanitary and other considerations.

4.3 Metering, Pricing and User Service Charges

The legal constraints on implementing water metering or user service charges schemes can be divided into three groups: (1) legislative control, (2) restrictions on utility revenue use, and (3) enforcement of policies. Each of these issues involves institutional as well as legal considerations.

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[1] Arther P. Brigham, "Washington Suburban Sanitary Commission Pioneers in Water-Saving", paper prepared by WSSC Public Information Office.

4.3.1 Legislative and Regulatory Controls on Rate-Setting

The controls to which water or sewer organizations are subject in setting rates clearly can affect the ability of such organizations to use rate-setting to achieve flow reduction.

The degree to which water and sewer utilities are regulated depends, for one thing, on whether they are privately- or publicly-owned. Thus, in the case of water utilities, though most are publicly-owned, many are privately-owned, and in most states (45) these are subject to quite detailed regulation by state utility commissions. According to a recent survey, state commissions have authority to regulate retail rates of privately-owned water utilities in 44 of those states, to prescribe fair rates of return in 40 states, uniform accounting forms in 43 states, and depreciation methods in 30 states.[1] A report by the "Joint Group" (of engineers and lawyers) notes, however, that there are "very few privately-owned sewage works and this study has disclosed none which is regulated by a state regulatory commission.[2]

With respect to publicly-owned water utilities and sewage works, the Joint Group notes, "in the great majority of states, [these] are not subject to regulation by any external authority, such as a state public utilities commission."[3] Specifically, Keig notes that in only 6 states are publicly-owned water systems so regulated (Indiana, Maine, Montana, Rhode Island, Wisconsin and West Virginia). Similar data on publicly-owned sewage utilities are not available, but the number of states in which they are regulated is probably as small or smaller.

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[1] Keig, "State Regulation of Water Utilities, "Publ. Util. Fort., Aug. 13, 1970.

[2] Joint Group, "Fundamental Considerations in Rates and Rate Structures for Water and Sewage Works," 12 Ohio State L.J. 170 (1951).

[3] Joint Group, ibid.

While direct state regulatory control is seldom exercised over water and sewage utilities--particularly publicly-owned ones-- they are subject to varying degrees of control through state constitutions, charters, court decisions, practices of long standing, and so on. These legal controls may specify, for example, the permissible sources of revenue. The Joint Group notes that "the law governing public works may require that the total annual revenue be derived solely from users, or solely from properties by general taxation or special assessment, or, occasionally, a combination of the two."[1]

The main point of interest is whether laws may prohibit water and sewage agencies from instituting charges which would encourage flow reduction--i.e., charges based on flows.[2] While no specific information is available, the number of instances where laws prohibit such charges, or where changing a law would be a serious obstacle, is probably small.

In particular, as a result of the Federal Water Pollution Control Act Amendments of 1972, user charges for sewage agencies are becoming common since the Act provides that to qualify for a construction grant, a sewage agency must recoup operation and maintenance costs through user charges (rather than ad valorem charges on property).[3]

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[1] Joint Group, ibid., 152

[2] This point is treated at greater length in EPA, Clean Water: Report to Congress 1975-76, Ch. 9.

[3] Public law 92-500, Section 204 (b) (1).

4.3.2 Constraints Due to Effects on Revenues

Given that a water or sewage agency can assess user charges based on flows, it is of interest to know whether there are constraints on the total revenues collected or on the use made of revenues, because such constraints can hinder the adoption of charges intended to achieve economically efficient use of the agency's resources.

For instance, setting a price equal to marginal cost could lead to increased revenue and profits, if the marginal cost of producing the quantity of water demanded were greater than the average cost of production. These additional profits can lead to problems of their own.

Privately-owned utilities, for example, are typically constrained to earning a "fair rate of return," and this may limit the utility's ability to earn additional profits, even though this might be desirable in terms of resource utilization.

Similarly, in publicly-owned utilities, there are often restrictions on the magnitude or use of utility revenues. For example, Pennsylvania law authorizing sewage charges requires that any surplus above a ten percent margin of safety be placed in the sewage sinking fund, and forbids any transfer of funds to general municipal funds. (Pennsylvania municipal water works are not, however, subject to such restriction.)[1] The Montana Public Utilities Commission ruled in 1948 that use of water revenues for purposes other than water utility operation constitutes a violation of the regulations of the Commission and of the principles of business operation.[2]

On the other hand, the Constitution of New York State allows municipalities to use profits from their public utilities for municipal purposes or for refunds to consumers. However, state law places a ceiling on the profits that can be earned by a public utility--a tax equivalent, equal to what whould be paid if privately owned, plus "a fair return on the value of the property used and useful in such public utility service."[3]

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[1] Joint Group, "Recommended Procedures for Establishing Fair Rates and Rate Structures," 12 Ohio State L.J. 186 (1951).

[2] *Ibid.*, 187.

[3] *Ibid.*, 187-188.

4.3.3 Examples in the Establishment of Flow-based Charges

In some widely-publicized cases where the adoption of metering and user charges has been at issue, the main obstacle to adoption has been not the legal constraints, but the question of cost-effectiveness and perhaps feelings of equity.

For example, the New York Times states, "Every serious study of the New York City water supply for three-quarters of a century has recommended the adoption of universal metering."[1] Metering is recommended because it would encourage water conservation, help in leak detection and repair, and discourage waste. Pressure on the city's water supplies and sewage treatment facilities would be reduced. It would also provide a more equitable means of collecting revenue for water services than the current method of collection.[2] At the present time, only 25 percent of the city's water supply is metered.

However, metering has been resisted by apartment house owners, by private home owners, and by some elected and appointed officials. Metering opponents point out that 87 percent of the people in New York City live in apartment buildings or multi-unit structures, and only 13 percent of the residences are single family homes.[3] Therefore, there are no large lawn areas to be watered, and lawn sprinkling is one of the uses of water most affected by universal metering. If leakage, and accounting for system flows, are problems, cannot these problems be solved other that by universal metering? The cost of various alternatives to the present system of metering and charges do not appear to have been definitively assesed.

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[1] Recommendations of the Commission, Water for Tomorrow; Temporary State Commission on the Water Supply Needs of Southeastern New York, 1973, p. 29.

[2] Measures to Reduce Water Consumption in Southeastern New York, Temporary State Commission on the Water Supply Needs of Southeastern New York, 1973, pp. 10-16.

[3] Recommendations of the Commission, Water for Tomorrow, Temporary State Commission on the Water Supply Needs of Southeastern New York, 1973, p. 30.

4.3.4 Enforcement Policies

The final significant legal constraint involves enforcement of the payment of water bills. The problem arises because state health codes require that water be provided for every building designed for human occupancy. The Commonwealth of Massachusets states in the State Sanitary Code that: "The owner shall provide for the occupant of every dwelling, dwelling unit, and rooming unit a supply of water sufficient in quantity and pressure to meet the ordinary needs of the occupant, connected with the public water supply system, or with any other source that the Board of Health has determined does not endanger the health of any potential user."[1] Shutting off a person's water amounts, therefore, to evicting him, and is used only as an extreme last resort.

Positive measures do exist for enforcing the payment of water bills. One way is to offer discounts for payments made on time; another way is to penalize late payment with interest charges. The water company can also require a deposit, or a payment in advance, or can hold the owner of the premises personally liable for payment. The water company can further deny service to those who have not paid past bills, which in effect leads up to the last and most extreme resort of shutting off water.

There are limitations on the authority of the water company to shut off service as a means of collecting charges. There must be a lien or express statutory authority, the charge must not be discriminatory or excessive, and shut-offs are improper where charges are in dispute. These restrictions mean that a statutory basis is necessary for service shut-offs; a court can rule that charges were discriminatory or excessive; and a court can refuse shut-off because of a claim of a faulty meter.[2] Nevertheless, shut-off has been upheld in some court cases.

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[1] Mass. State Sanitary Code Art. II, Minimum Standards of fitness for Human Habitation, Regulation 4 (1969)

[2] Joint Group, "Fundamental Considerations in Rates and Rate Structures for Water and Sewage Works," 12 Ohio State U. L. J. 261.

The principal constraint is the Constitutional (State and Fourteenth Amendment) due process requirement for pre-shut-off hearing. This hearing is often too expensive for utility companies to undertake regularly, leading to many bill compromises.

4.3.5. Summary

The institutional and legal constraints on the implementation of metering, pricing or user service charges involve a choice between state and municipal control. In order to meet special needs of individual municipalities decentralization is necessary. However, local units in many states do not, under existing legislation, have the freedom of action needed to enable them to apply the various pricing schemes effectively. Due to various restrictions on the use of utility revenues, metering, pricing and user service charges must be carefully designed to comply with existing legislation, or legislative changes must be made.

User charge policies are commonly enforced by positive incentives, on the one hand (e.g., discounts for payments made on time), and penalties (e.g., shut-off), on the other hand.

4.4 Water Recycling

The water-recycled toilet uses water from the shower or the washing machine in the toilet since potable water is not needed for flushing. Two possible main conflicts arise with this option under most plumbing codes. One is that the use of recycled water might involve a cross-connection of potable and nonpotable water; the second is related to sanitation requirements.

4.4.1 Cross-Connections

All plumbing codes devote a large amount of discussion to condemning cross-connections. Ira Markwood, Manager of Surveillance Section of the Illinois Division of Public Water Supplies, wrote an article entitled "Cross-Connections-- Legal or Lethal?" for that state's Environmental Protection Agency. He described in this paper what cross-connections are and their hazards. In order to explain how easy it is for contamination to occur due to cross-connection, Markwood provides an illustration:

> " Suppose it is necessary to repair a washer on the first floor sink of a two story house with sinks on both floors. The normal procedure is to shut off the water to the tap which needs repair, change the washer, and turn the water back on. If there is a separate set of shut-off valves for this tap there is no problem. But very frequently it is necessary to close the main inlet to the building. Then, when the tap is disassembled for repair the weight of the water above it, particularly if the tap at the top floor is open, will allow the pipe to empty. If you are upstairs at the open tap when this happens, you would hear a distinct sucking sound as air is drawn back into the pipe. Now suppose that someone has put onto the tap one of those hose sprays which are quite common, and has left it in the sink when it is filled with soapy water. It's obvious what will happen, the soapy water will be drawn into the pipe line. The whole theory of danger from cross-connection is as simple as that."[1]

The chances of hazardous cross-connections are very slim; but due to the very serious consequences of nonpotable water being siphoned into a potable water supply, extreme precautions are taken to prevent such an occurrence. There is considerable controversy whether recycled water does or does not involve cross-connections. Some experts claim that building inspectors would not allow installation of recycled-water toilets for fear that something could go wrong. Other experts claim that it would be an engineering impossibility to satisfy the cross-connection requirements of plumbing codes and still maintain an adequate amount of water for toilet use. An institutional constraint is that building inspectors might be opposed to the idea because of its novelty, though if the device were uniformly installed it would be viewed more favorable. The reason for this stipulation is technical. Suppose a tenant installed a water-recycled toilet and after a few years moved out; the next tenant might come in with a ice-maker and accidently tap the nonpotable source. This is the sort of rare accident which building inspectors take very seriously.

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[1] Markwood, "Cross-Connections - Legal or Lethal?" State of Illinois Environmental Protection Agency, Division of Public Water Supplies (1973).

There are numerous examples of plumbing codes which restrict cross-connections of potable and nonpotable water. The Southern Standard Plumbing Code stipulates:

> "Potable water supply piping, water discharge outlets, backflow prevention devices or similar equipment shall not be so located as to make possible their submergence in any contaminated or polluted liquid or substance."[1]

Usually some kind of device to prevent backflow is necessary. Additionally, Section 1204.2 of the code states:

> "Before any device for the prevention of backflow or back-siphonage is installed, it shall have been certified as meeting the requirements of ANSI A 40.6-1943 by a recognized testing laboratory acceptable to the Plumbing Official. Devices installed in a potable water supply for protection against backflow shall be maintained in good working condition by the person or persons having control of such devices. The Plumbing Official

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[1] Southern Standard Plumbing Code Ch.12,§ 1204.1 (1971).

> having jurisdiction may inspect such devices and if found to be defective or inoperative, shall require the replacement of the device."[1]

The City of Atlanta plumbing code stipulates:

> "Cross-connections are prohibited except when and where approved by the authority having jurisdiction, suitable protective devices such as the reduced pressure zone backflow preventer or equal are installed, tested and maintained to insure proper operation on a continuing basis."[2]

The Wisconsin plumbing code states:

> "Cross-connections are prohibited except as approved by the department when suitable protective devices such as the reduced pressure zone backflow preventer or equal are installed, tested, and maintained to insure proper operation on a continuing basis."[3]

It is important to understand the correlation between water-recycled toilets and potable water in order to minimize the potential hazards of cross-connection. Water is recycled from a shower or washing machine into the toilet. Therefore, the toilet must be disconnected from the potable water supply. If the engineering involved prevents any connection from the toilet to the potable water supply, then there are no legal constraints to the water-recycled toilet. However, if there is a deficient supply of water to be recycled, a subsequent need for make-up water might develop which would involve potable water. In this situation, the legal constraints could be numerous. Backflow prevention devices might not pass the building inspection. Some states do not allow any forms of cross-connection. The Illinois Department of Public Health Rules and Regulations stipulates in Rule 3.60:

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[1] Southern Standard Plumbing Code Ch. 12 § 1204.2 (1971).

[2] Atlanta, Ga. Plumbing Code § P-1605.3 (1972).

[3] Wis. Plumbing Code, § H 62.14(c) (1972).

> "No physical connection shall be permitted between a public water supply and any other waste supply not of equal or better bacteriological and chemical quality as determined by inspection and analyses. There will be no arrangement or connection by which an unsafe water may enter a public water supply."[1]

The N.Y. Bldg. Code Subart. 1601.0 Section C26-1601.3 stipulates:

> "No person shall connect water piping supplied directly from street water mains to other sources and no cross-connection shall be made between the potable water distribution system and any portion of waste or soil systems, or between the potable water distribution system and fixtures or devices that may contaminate, pollute or otherwise render the water nonpotable."[2]

The National Plumbing Code Handbook states,

> "Nonpotable water may be used for flushing water closets and urinals and other fixtures not requiring potable water, provided such water shall not be accessible for drinking or culinary purposes."[3]

The best way of preventing backflow is with an air gap, that is, an air space between potable and nonpotable water. The space between a kitchen faucet and the sink drain is an example of an airgap. Most plumbing codes have strict provisions for the minimum air gaps in plumbing fixtures, and any holding tank for recycled water would have to comply with this code. The potable water source outlet to the storage tank must also meet the various requirements of plumbing codes concerning water outlets, air gaps, and backflow devices.

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[1] Ill. Dept. of Public Health Rules and Regulations, Rule 3.60 (1970).

[2] N.Y. Bldg. Code, Subart. 1601.0, § C26-1601.3 (1973).

[3] Manus, National Plumbing Code Handbook § 10.13, New York (1971).

An alternative to all these requirements would be to allow water-recycled toilets only in those households that use enough water to recycle. This choice entails constraints because building inspectors are more suspicious of devices that are not uniform. Also, demand and use of water in a particular house varies with appliance-use and personal habits.

4.4.2 Sanitary Conditions

The last consideration is one of sanitary conditions. The Department of Health in every state usually specifies that dwelling units must maintain clean and sanitary plumbing fixtures. Recycled water facilities that are properly installed will meet these requirements. However, conditions could exist which would violate the regulations of the Department of Health. The Mass. State Sanitary Code stipulates,

> "Every occupant of a dwelling unit shall keep all toilets, wash basins, sinks, showers, and bathtubs in a clean and sanitary condition."[1]

The holding tank of water to be recycled would have to conform to sanitary regulations. If a potable water connection is made, then the rules are fairly specific as to cleaning, lining, painting or repairing of the water tank. The National Plumbing Code Handbook stipulates that:

> "Water pumps, tanks, filters, softeners, and all other appliances and devices shall be protected against contamination."[2]

There are also regulations governing the disinfection of potable water-system plumbing.

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[1] Mass. State Sanitary Code, Art. II, Minimum Standards of Fitness for Human Habitation, Regulation 9.4 (1969).

[2] Manus, National Plumbing Code Handbook, § 10.7, New York (1971).

4.4.3 Summary

The water-recycled toilet involves more serious legal constraints than any other water-saving device due to the problems of cross-connections and sanition. Building authorities will allow the use of the water-recycled toilet only if engineering technology can solve these problems.

4.5 Conclusions

The various problems with water-saving devices, metering and the water-recycled toilet have been described but not solved. Metering, pricing and user service charges involve more institutional and legal conflicts than the other options but are the most practical measures to reduce waste water flow. The installation of water-saving devices should naturally follow if the price of water is raised. However, requiring installation of water-saving devices for new or renovated homes involves fewer legal problems than requiring all homes to install the devices. Finally, the water-recycled toilet has more legal constraints than any other water-saving device. Only if engineering technology can eliminate the problems of cross-connections and sanitary considerations will building authorities allow the use of the water-recylced toilet.

CHAPTER FIVE

COST-EFFECTIVENESS OF METERING AND PRICING

This chapter discusses the cost-effectiveness of metering and pricing schemes, based on the results of the computer Policy Analysis Model (PAM). Section 5.1, a general description of the model, outlines the required input data and the generated output. Section 5.2 describes both qualitative and mathematical components of the model. Section 5.3 is a presentation of the results of analysis, and conclusions follow in Section 5.4. Some additional comments pertaining to this model are given in Section 5.5.

5.1 General Description of PAM

The purpose of the Policy Analysis Model is to evaluate the cost and the benefits of metering and pricing schemes. These schemes are evaluated in terms of economic efficiency measured by the sum of consumer surplus and producer surplus, distributional effect across income classes, and the ability to conserve water, so that national and regional impacts can be assessed. Models of this sort can help to determine the effects of various contemplated rate structures on the community. In conjunction with an analysis of political and social values in an area, such an analysis can in turn be a helpful input into a policymaker's decision process. For this study the model is primarily intended to explore the impact of the more common rate structures, increasing block rate, decreasing block rate, uniform unit rate and flat rate -- under the assumption of specific sets of system cost functions. In addition, economic analysis is used to explain the results.

There are several points that should be discussed pertaining to the evaluation of rate structures. First, it is hard to make judgements about a rate structure *per se*, since the impact depends on the detailed design of the rate schedule -- e.g., on such matters as the cutoff points for various consumption blocks -- and on the rate level as well as on the type of rate structure itself. However, most water utility systems set their rates in such a way that the

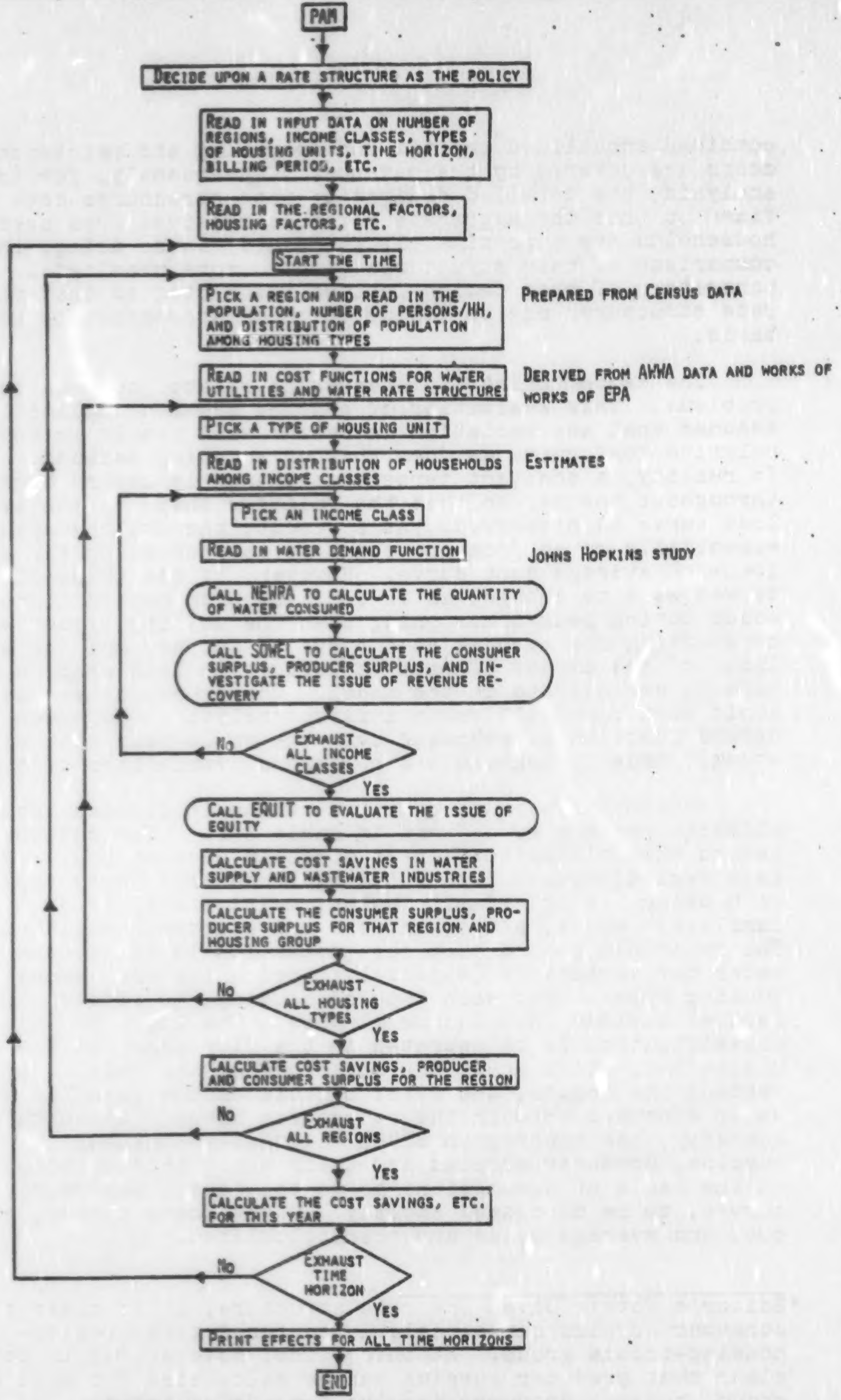
PAM
DECIDE UPON A RATE STRUCTURE AS THE POLICY
READ IN INPUT DATA ON NUMBER OF REGIONS, INCOME CLASSES, TYPES OF HOUSING UNITS, TIME HORIZON, BILLING PERIOD, ETC.
READ IN THE REGIONAL FACTORS, HOUSING FACTORS, ETC.
START THE TIME
PICK A REGION AND READ IN THE POPULATION, NUMBER OF PERSONS/HH, AND DISTRIBUTION OF POPULATION AMONG HOUSING TYPES
PREPARED FROM CENSUS DATA
READ IN COST FUNCTIONS FOR WATER UTILITIES AND WATER RATE STRUCTURE
DERIVED FROM AWWA DATA AND WORKS OF WORKS OF EPA
PICK A TYPE OF HOUSING UNIT
READ IN DISTRIBUTION OF HOUSEHOLDS AMONG INCOME CLASSES
ESTIMATES
PICK AN INCOME CLASS
READ IN WATER DEMAND FUNCTION
JOHNS HOPKINS STUDY
CALL NEWPA TO CALCULATE THE QUANTITY OF WATER CONSUMED
CALL SOWEL TO CALCULATE THE CONSUMER SURPLUS, PRODUCER SURPLUS, AND INVESTIGATE THE ISSUE OF REVENUE RECOVERY
NO
EXHAUST ALL INCOME CLASSES
YES
CALL EQUIT TO EVALUATE THE ISSUE OF EQUITY
CALCULATE COST SAVINGS IN WATER SUPPLY AND WASTEWATER INDUSTRIES
CALCULATE THE CONSUMER SURPLUS, PRODUCER SURPLUS FOR THAT REGION AND HOUSING GROUP
NO
EXHAUST ALL HOUSING TYPES
YES
CALCULATE COST SAVINGS, PRODUCER AND CONSUMER SURPLUS FOR THE REGION
NO
EXHAUST ALL REGIONS
YES
CALCULATE THE COST SAVINGS, ETC. FOR THIS YEAR
NO
EXHAUST TIME HORIZON
YES
PRINT EFFECTS FOR ALL TIME HORIZONS
END

FIGURE 5-1. THIS FIGURE DISPLAYS A FLOW CHART OF THE POLICY ANALYSIS MODEL (PAM) TO EVALUATE METERING AND PRICING SCHEMES.

combined annualized capital and operating and maintenance costs are covered by the revenue. Consequently, for this analysis, the detailed designs of rate structures have been fixed so that the aggregate revenues received from average households are approximately the same. In so doing, the comparison of rate structures becomes more meaningful. The parameters of rate design becomes restricted so that various rate structures may be evaluated on an appropriately comparable basis.

The second point of interest is related to peak load problems. This evaluation of pricing schemes implicitly assumes that any variation in demand will result in the same relative load curve as does that of existing demands. In reality, a constant percentage change in demand occurs throughout the day so that the relative shape of the system load curve is preserved. As a result, the utility system essentially moves from one point to another along the same long-run average cost curve. However, if the shape of load curves were to change, as is the case when demand increases occur during peak times only, then the utility system would be shifting one average cost curve to another and the whole issue of the impact of rate structures on load shape would have to be included in the model. The approach here is to avoid such complexities in a first analysis. Moreover, the demand function is averaged over the whole year with no attempt made to segregate the seasonal variations of demand.

This model assumes that the nation is diveded into seven climatic regions as defined in Table 5-1. (The rationale behind this classification is given in Section 5.2.) For each region, households are categorized into three types of housing: single-family units, multi-family (2-5 families) units, and townhouses and apartment buildings. The rationale behind such categorization is to capture the water use variations (especially sprinkling use) among housing types. For each type of housing, households are further divided into income classes. The logic of this classification is illustrated in the flow chart of PAM in Figure 5-1, which shows the structure of the model. After reading the inputs, the model calculates the quantity of water consumed through the subprogram NEWRA. Given this quantity, the subprogram SOWEL calculates consumer surplus, producer surplus and their sum.* This is done on the basis of assumptions as to the demand and supply curves, to be discussed shortly. Given these curves, average cost and average price are then calculated.

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*Editor's Note: Given the rate structure, it is clear that consumer surplus can be calculated for a given region-housing-income group. At this point, however, it is not clear that producer surplus can be calculated for such a group, because producer surplus depends on the cost of producing the output demanded by all groups.

TABLE 5-1

CONSTITUENTS OF THE SEVEN REGIONS FOR THE PAM

Region	I	II	III	IV	V	VI	VII
STATES	Maine New Hampshire Vermont Massachusetts Rhode Island Connecticut New York New Jersey Pennsylvania West Virginia Maryland Delaware Ohio Michigan Indiana Kentucky Washington, D.C.	North Carolina South Carolina Georgia Florida Tennessee Alabama Mississippi Louisiana Arkansas	Wisconsin Illinois Iowa Missouri North Dakota South Dakota Nebraska	Kansas Oklahoma Texas	Montana Idaho Wyoming Utah Colorado	New Mexico Arizona Nevada California	Washington Oregon
Annual Rainfall Range cm (inches)	81-122 (31-48)	122-163 (48-64)	41-122 (16-48)	41-122 (16-48)	0-81 (0-32)	0-41 (0-16)	41-325 (16-128)
Pan [a]Evaporation cm (inches)	81-122 (31-48)	122-163 (48-64)	81-203 (32-80)	71-163 (28-64)	81-203 (32-80)	122-366 (48-144)	0-163 (0-64)

[a] Pan Evaporation is defined as the measured water loss from a metal pan four feet in diameter by 10 inches deep and set very close to the ground.

This is done separately for each income class and the discrimination effect across income classes is analyzed via the index discussed elsewhere. Cost savings in capacity expansions and operating and maintenance of water utilities and wastewater industries, as well as consumer surplus and producer surplus, are computed for the region. Similar sequences of computations are performed for the other regions to obtain the national totals for a single year. Repeating these calculations for other years leads to the outputs for evaluating the particular pricing scheme for the nation over the time period in question.

For inputs, the model needs the following for each region, each type of housing unit, and each income class: population, household density, water demand function, cost functions for water supply and sewer services, and a specification of the pricing scheme.

In fact, the model was run for two different water supply cost functions: increasing average costs and decreasing average costs. Moreover, the level of each pricing scheme was varied to allow for a separate evaluation of high, medium and low utility rates. (A more detailed discussion can be found in Section 5.2.3.)

5.2 Mathematical Modeling

This section discusses the theory behind the formulation of the computer model with discussions on the rationale behind the formulation of each individual model component, which includes the regional classification, the water use demand, water supply cost functions, sewer services cost functions, and the welfare analysis of rate structures. Prior to the discussion of these formulations, a few assumptions pertaining to this model are stated below:

1. For simplicity, the water use patterns, rate structures, cost curves, housing and income distributions are assumed not to vary within each region.

2. Each model region is made up of communities, each with a population of 50,000. Within the region the number of persons per household is constant. However, varying number of communities make up the appropriate population for each region.

3. The rate structures considered are for combined water and sewer services since the dependence on price in the water demand function is for the combined services. For details, please refer to Section 5.2.2.

4. The model is deterministic.

5.2.1 Regional Classification

One of the major rationales for dividing the nation into regions is to recognize the variation in sprinkling water use due to climate.[1,2] As alluded to in Section 3.1, more arid regions require larger amounts of water for lawn sprinkling, thus leading to different regional water use patterns. Moreover, these regions may incur different costs for water utility services due to regional differences. Consequently, regional classification is in order. The analysis is simplified by dividing the nation into small and manageable regions. It would be too complicated if it were conducted for the whole nation.

The nation is divided into seven regions as shown in Table 5-1. States are grouped together to form these seven regions according to annual rainfall and pan evaporation rates. Using Region I as the norm for calculating water use patterns and water supply cost, regional factors can be estimated for the other regions. From the results of the literature review,[3] water use patterns for different parts of the nation are available. Dividing the per capita water consumption data from each region by that of Region I, regional water consumption factors are obtained. Similarly, based on the water supply cost data from the American Water Works Association,[4] corresponding water supply cost factors can be computed.

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[1] F.P. Linaweaver, Jr., and Jerome B. Wolff, Report II on Phase Two, June 1965: 35-43.

[2] Charles W. Howe and F.P. Linaweaver, Jr., "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure," Water Resources Research, vol. 3, no. 1 (First Quarter, 1967); 13-52.

[3] Howe and Linaweaver, "Impact of Price on Water Demand."

[4] American Water Works Association, Operating Data for Water Utilities, 1970 and 1965, AWWA Statistical Report, AWWA No. 20112.

5.2.2 Water Use Demand Model

Water use varies from region to region, and it also varies with family income, type of housing, and price, as discussed in Chapter Three. This model formulation closely follows that of the Johns Hopkins Study.[1,2,3] Domestic water use is divided into two categories: indoor and outdoor (or sprinkling). The following assumptions were made to obtain the water demand model for this study.

1. Water use is composed of two major components: indoor and sprinkling. There is regional variation in water use.

2. Water use variation among income classes is taken into account by the income elasticity, which may have housing value as a surrogate.

3. Sprinkling use differs for different types of housing and income classes. The variation is incorporated by the housing value variable and housing type factor. The housing type factor is similar to the regional factor except that the former takes the water use variation over housing

4. Sprinkling use occurs for only three months of the year.

5. Water demand is equal to sewage demand.

Given these assumptions, the following illustrative water demand functions were developed, based largely on the results of Howe and Linaweaver:[4]

For metered households, whether single-family units or apartment buildings, domestic water use per dwelling unit per day in gallons, q_d depends on the value of the housing unit v in thousands of dollars, and the unit price of combined water and sewer services p in cents/thousand gallons, as follows:

$$q_d = 206 + 3.47v - 1.30p \qquad (1)$$

---

[1] Linaweaver and Wolf, Report II.

[2] Howe and Linaweaver, "Impact of Price on Water Demand."

[3] A.P. Grima, Residential Water Demand - Alternative Choices for Management. (U. of Toronto Press, 1972).

[4] Howe and Linaweaver, "Impact of Price on Water Demand."

The corresponding sprinkling use q_s is:*

$$q_s = (10^{3.053})p^{-0.703}\,v^{0.429} \tag{2}$$

Thus, the average water use per dwelling unit per day q_m for a given housing type i at region n is:

$$q_m = [q_d + 0.25\,h_i q_s]R_n \tag{3}$$

where h_i is the housing type factor for type i, and R_n the regional factor for water consumption for region n.

In other words:

$$q_m = [(206 + 3.47v - 1.30p)+(0.25)(10^{3.053})p^{-0.703}v^{0.429}h_i]R_n \tag{4}$$

where the factor 0.25 takes into account the fact that there is sprinkling for only three months of the year.

For unmetered households, domestic water use q_d per household per day in gallons depends on the value of the housing unit, v, and the number of persons in the household, d_p.

$$q_d = 28.9 + 4.39v + 33.6d_p \tag{5}$$

The corresponding sprinkling use q_s per dwelling unit per day in gallons is:

$$q_s = (100)v^{0.783} \tag{6}$$

---

* Editor's Note: Equation (2) is the sprinking demand equation for western areas presented in Howe and Linaweaver, "Impact of Price on Water Demand", and is used here for all regions (adjusted by the regional constants, R_n). In the cited paper, the equation for eastern sprinkling demand includes a variable for irrigable area of a home whose estimated coefficient is negative, opposite to what one would expect. Since running the calculations, a more recent and consistent set of equations from the same study was found in an unpublished Appendix to Charles W. Howe et al., Future Water Demands, p. 87, obtained from Wm. J. Vaughn. Resources for the Future, Washington, D.C.

It may also be noted that house values and water prices are in terms of 1963 dollars, and hence that the equations should be adjusted if prices are atated in dollars of another year.

so that the water use per dwelling unit per day for unmetered households q_u is:

$$q_u = [(28.9 + 4.39v + 33.6d_p) + (0.25)(100)v^{0.783}h_i]R_n \qquad (7)$$

where h_i is the housing type factor for type i, and R_n the regional factor for region n. This formulation for unmetered households will be used to estimate the water demand in areas where flat rates are used.

5.2.3 Water Supply Cost Functions

A water supply system is composed of several components, each with its own capital cost and operating and maintenance costs. Cost functions for each of these components can be grouped together to form the appropriate cost functions for the water supply system. These components include impounding reservoirs, intake and pumping stations, transmission pipelines, raw water storage, water treatment plants and storage, and treated water pumping stations. The costs of these components together with the engineering, administrative and financing costs as well as land, rights of way and water right costs form the water supply cost function.

There are a few comments that should be noted about these cost functions. Firstly, these functions vary over different regions, thus prompting the need for regional cost factors to capture such regional variations. For example, the unit cost of water supply in Southern California is higher than that in the Northeast because water has to be transported over a long distance from Northern California. Secondly, all monetary values computed in this model are inflated to 1974 dollars.

From the viewpoint of rational social choices, the cost functions used should include not only accounting costs but also social costs like environmental costs and other externalities as well as any other opportunity costs that do not have market prices. It may turn out, for example, that diverting water for water supply could deprive the recreational users of the opportunity of boating or fishing. Such opportunity costs should also be included in the cost functions. Unfortunately, it is extremely difficult to estimate such costs, which partially explains why in this report the cost functions while based on real data, are in part hypothetical -- especially the rising average cost function we employ below. Because the main purpose of constructing these cost functions is to evaluate rate structures from an overall perspective, any arbitrariness in this regard should not affect the results obtained.

The next comment pertains to the nature of the cost functions. In the literature review conducted for this project, all cost functions provided decreasing average cost functions, that is, economies of scale always existed. This assumption was supported by the data from American Water Works Association[1] and from Ford and Warford.[2] Decreasing cost functions imply that any capacity expansion would result in an even smaller average cost. Previously this was the case where municipal systems were not utilized up to their maximum capacities, but it may not be true in some cities now. Water resources may become increasingly scarce. Communities may expand so much that they compete for water supplies. As a result, the marginal cost of additional water may well be higher than before, so that average cost function may now be rising instead. Consequently, there were two formulations of water supply cost functions developed, and they are reported below.

1. Decreasing average cost function - this cost function was based on the material reported by Black & Veatch.[3] Both the capital cost function and O&M cost function are summarized in Table 5-2 and 5-3. The following symbols were used:

   Q = daily water requirement in million gallons per day.

---

[1] AWWA, Operating Data.

[2] J.L. Ford and J.J. Warford, "Cost Functions for the Water Industry," Journal of Industrial Economics (September 1965): 53-63.

[3] Black and Veatch, Standard Procedures for Estimating Costs of Conventional Water Supplies, Comprehensive Report (Kansas City, Missouri: Black & Veatch, [1963]).

A(r,n) = amortization factor assuming r percent for n years.

K = annualized capital cost.

Capital costs are made up of the components in Table 5-2. O&M costs are composed of three major categories: general costs, chemicals costs, and pumping costs. General costs include costs of labor and supplies for operating the various components of water supply systems, but they do not include costs of chemicals and pumping. The constituents of each category are shown in Table 5-3. The summation of these costs leads to the annual O&M costs of water supply.

2. Increasing average cost function - The data for developing this rising average cost function came from Fairfax County Water Authority.[1] A simple curve fitting scheme was used to derive the annualized capital expenditure K_c and annual O&M costs K_{OM} for capacity expansions leading to the following:

$$K_c = 295.3 \ Q^{2.182} \qquad (8)$$

$$K_{OM} = 204.89 \ Q^{2.464} \qquad (9)$$

These costs are in 1966 dollars, which will be inflated to 1974 dollars for this analysis. The fact that the values of exponents of Q in these equations exceed one shows that the average cost functions have rising slopes, so that diseconomy of scale prevails.

For both types of average cost functions, energy cost is assumed to be a percentage of O&M costs. This cost is estimated to be 20 percent of the O&M costs,[2] i.e.,

$$K_E = 0.2 \ K_{OM} \qquad (10)$$

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[1] Greeley and Hansen Engineers, Fairfax County Water Authority Report on Ten-Year Financial Program. April 1974.

[2] Personal communication with Mr. Fred Welch, Department of Public Works, Wellesley, Massachusetts, January 1975.

TABLE 5-2

CAPITAL COST FUNCTION FOR WATER SUPPLY SYSTEM

(in 1963 dollars)

COMPONENT OF SYSTEM	TOTAL CAPITAL COST
Impounding reservoir	$CA = 0.54 \times 10^6 \times (2Q)^{0.61}$
Intake and pumping station	$CB = 15000 + 45460\ Q$
Transmission pipeline	$CC = 18260\ Q$
Raw water storage	$CE = 15000 + 58600\ Q$
Water treatment plant & storage	$CF = 280000 + 17440\ Q$
Treated water pumping station	$CG = 38000 + 28340\ Q$
Engineering Administration & Financing	10% of total construction cost
Meter purchase & construction (annualized cost)	$CH = 24922\ Q$

Annualized Capital Cost Function

$$K_c = 1.1 \times A(r,n)[CA + CB + CC + CE + CF + CG] + CH$$

where A(r,n) is the amortization factor.

TABLE 5-3

ANNUAL O & M COSTS K_{OM} FOR WATER SUPPLY SYSTEMS (In 1963 DOLLARS)

	COMPONENTS	COST FUNCTIONS
A.	General Costs	
	Supplies	$0.007 \times 10^3 \times 365\ Q$
	Pipeline [a]	$0.0025 \times CC$
	Raw water storage [a]	$0.005 \times CE$
	Treatment & storage	$21900\ Q^{0.737}$
	Disinfection	$0.004 \times 10^3 \times 365\ Q$
	Pumping	$8030\ Q^{0.688}$
	Meter Inspection & Maintenance	$1122\ Q$
B.	Chemicals Costs	$0.03 \times 10^3 \times 365\ Q$
C.	Pumping Costs	$0.014 \times 10^3 \times 365\ Q$

[a] CC and CE are total construction costs for pipelines and raw water storage respectively.

5.2.4 Sewer Service Cost Functions

Sewer service costs are composed of capital and O&M expenditures for two different components of the service: wastewater collection, and waste treatment. The following assumptions are made pertaining to the cost model:

1. Waste treatment processes comprised of primary sedimentation, activated sludge treatment, and
2. Energy cost for wastewater interception and collection is negligible.
3. Where appropriate, energy cost is given as a functional form, otherwise it is a percentage of O&M cost.
4. There is insignificant regional variation in sewer service costs.

Wastewater collection and interception is discussed first, followed by a description of treatment costs. Most of these results are from EPA[1] and the works of Smith and Eilers,[2] Michel and Johnson.[3]

Sewers, interceptors and pumping stations are required for wastewater collection and interception. The capital expenditure per capita, K (in 1968 dollars), depends on population, p, as follows:[4] *

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[1] EPA, Guidelines for Cost Estimates of Municipal Wastewater Systems. Office of Water Programs Operations, Municipal Wastewater Systems Division, February 1973 .

[2] R. Smith and R. G. Eilers, Cost to the Consumer of Collecting and Treating Wastewater in the United States, FWQA, Cincinnati, Ohio, July 1970.

[3] R. L. Michel and W. W. Johnson, Costs and Man-Hours for Operation and Maintenance of Municipal Wastewater Treatment Plants, 1957-1970, Construction Grants and Engineering Branch, Division of State and Local Programs, EPA, October 1970.

[4] Smith, Cost to the Consumer, Table 3.

*Editor's note: Equation (11) actually refers only to ancillary works of a treatment plant (interceptors, pumping stations and outfalls). The capital costs for collection sewers, which are substantial, were inadvertently omitted in the calculation. In terms of 1968 dollars, according to the Smith and Eilers cost functions, the capital cost of ancillary works is $33/capita and for collection sewers $160/capita for a city of 50,000 people. The calculation is the text does include, however, O&M costs for the collection system.

$$K'_c = 86.26\ P^{-0.0896} \qquad (11)$$

Multiplying each side by P, and assuming that the inflation factor is r (assumed to be 7 percent per year), the total capital expenditure per community for 1974 becomes:

$$K_c = P\ K'_c\ e^{6r} \qquad (12)$$

$$K_c = 86.26\ e^{6r} P^{\ 0.9104} \qquad (13)$$

where e^{6r} converts the 1968 dollars into 1974 dollars.

It is assumed that each person generates a waste flow of 454 liters/day[1] (120 gpcd), so that the annual capital expenditure for 1974 becomes:

$$K_c = 86.26\ e^{6r} \left(\frac{Q}{120}\right)^{0.9104} \times A \qquad (14)$$

where Q is the daily wastewater flow from the community in gallons and A the amortization factor at 7 percent over 30 years. Isard and Coughlin[2] estimate O&M costs of wastewater collection of 20.3 cents per meter of sewer per year (6 cents/ft/yr). This is supported by data collected by Smith and Eilers.[3] Assuming that a community of 50,000 people has a sewer network whose total length is 357,000 meters (222 miles), total annual O&M cost for the community is:

$$K'_{OM} = (0.203)\ 357{,}000\ e^{6r} \qquad (15)$$

---

[1] This number takes into account infiltration and inflow.

[2] Isard and R.E. Coughlin, Municipal Costs and Revenues Resulting from Community Growth (Chandler-Davis Publishing Co., 1957).

[3] Smith, Cost to the Consumer.

Assuming a wasteflow of 454 liters (120 gallons) per person per day, and a linear relationship between population and the length of the sewer network, the O&M cost, K_{OM}, can be expressed in terms of wastewater flow per day, Q:

$$K_{OM} = 0.203\ e^{6r}\ \frac{357{,}000Q}{(50{,}000)\ (120)} \tag{16}$$

Since the energy cost, K_E, is assumed to be insignificant:

$$K_E = 0 \tag{17}$$

The discussion on waste treatment costs is divided into three parts: capital expenditure, O&M and energy. The model follows closely that of Michel[1] and the EPA.[2].

Capital cost for waste treatment consists of capital costs for conventional primary sedimentation, activated sludge treatment, and chlorination. This total capital cost, K_c, for waste treatment on a per capita basis is:[3]

$$K_c' = 912.73\ P^{-0.3088} \tag{18}$$

Cost is converted from 1968 to 1974 dollars by multiplying the equation by e^{6r}. P is Q/120 as derived prior to Eqn. (14). Making these substitutions, the annualized capital cost per year, K_c, is obtained:

$$K_c = A \times 912.73\ \left(\frac{Q}{120}\right)^{0.6912} \times e^{6r} \tag{19}$$

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[1] R.L. Michel, "Costs and Manpower for Municipal Wastewater Treatment Plant Operation and Maintenance, 1965-1968," JWPCF (November 1970): 1883-1910.

[2] EPA, Guidelines for Cost Estimates.

[3] Smith, Cost to the Consumer.

where A is the amortization factor for 7 percent over 20 years.

Similarly, O&M costs are as follows:[1]

$$K_{OM} = 30.1 \left(\frac{Q}{120}\right)^{0.754} \quad e^{6r} \tag{20}$$

The annual energy cost for waste treatment, K_E, is:[2]

$$K_E = 10^{3.8251}\left(\frac{Q}{10^6}\right)^{0.5582} \quad e^{6r} \tag{21}$$

Simplifying the equation, the expression for the annual energy cost becomes:

$$K_E = 10^{0.4759} Q^{0.5582} \quad e^{6r} \tag{22}$$

5.2.5 Welfare Analysis of Rate Structures

This section discusses the criteria used for evaluating the various rate structures. These criteria are: economic efficiency as measured by the sum of consumer surplus and producer surplus, discriminatory effects, revenue adequacy, and water conservation.

5.2.5.1 Economic Efficiency

Our measure of economic efficiency is the excess of consumer satisfaction from a good over the cost of the resources used in its production. In diagrammatic terms it is the area under the demand curve less the cost of production. In other words it is the sum of "consumer surplus" and "producers surplus," to use the technical economic terms. Consumer surplus is the difference between consumers' willingness to pay for a good and consumers' actual expenditures for the good. Producer surplus is the excess of total revenue (which is the same as consumers' actual expenditure) over the production cost. As a result, the sum of consumer surplus and producer surplus measures the gains to both, and hence is an indication of the social welfare society obtains from production of a commodity.

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[1] Michel, "Costs and Manpower."

[2] Michel, "Costs and Manpower."

The following discussion covers two points: how social welfare may be calculated and pricing conditions for its maximization. For simplicity, we begin with the case of uniform unit rate pricing structure.

Figure 5-2 shows an average cost curve (AC) and its related marginal cost curve (MC), and a demand curve (DD). Given a price P_1, the households would choose to consume Q_1 and the consumer surplus would be the area under the demand curve ($OABQ_1$), less household expenditures (OP_1BQ_1)-- i.e., the triangle AP_1B. Producer surplus is revenue (OP_1BQ_1) less total cost (OC_1DQ_1), or the rectangle (C_1P_1BD). Hence, the sum of the two surpluses (social welfare) is C_1ABD.

The question of economic efficiency can be considered most simply by dealing with marginal quantities. On the benefit side, the incremental value of one more unit of consumption is given by the height of the demand curve; and the incremental cost of one more unit is given by the marginal cost curve. Hence, it can be shown that at Q_1, the addition to social welfare from one additional unit of consumption is BE per unit. Increasing output will add to net welfare up to an output of Q_2, where MC equals the value of the Q_2 th unit. Our welfare measure at this point is at a maximum, and may be calculated as before.

In general, it is the case that marginal cost pricing will lead to a maximum for our welfare index. However, pricing systems other than the uniform unit rate one might cause this to occur. For instance, consider the case shown in Figure 5-3, where average costs are declining over the range of outputs of interest.

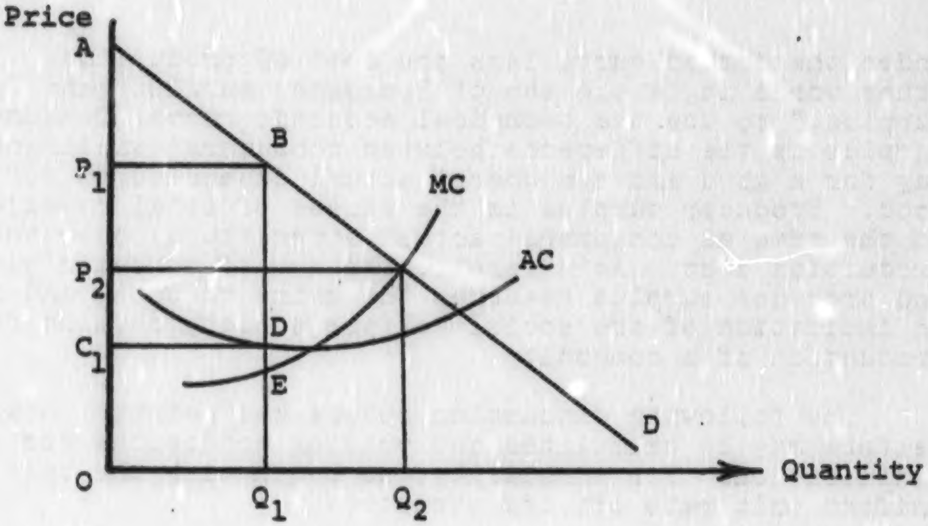

Figure 5-2. This figure illustrates the consumer and producer surplus for increasing average cost function.

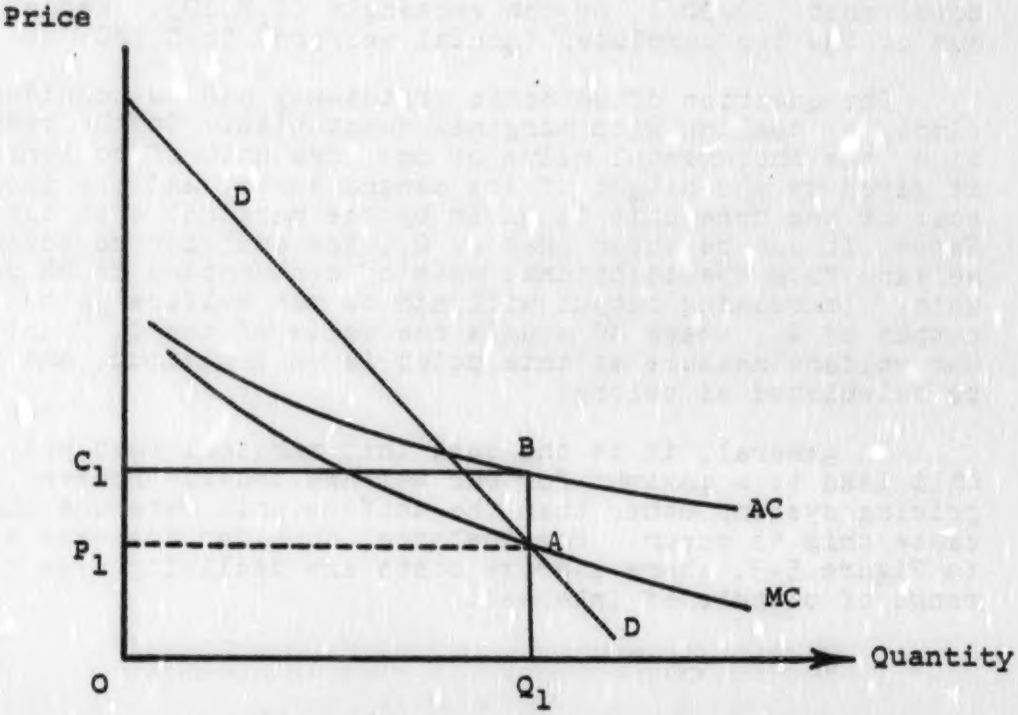

Figure 5-3. This figure illustrates the calculation of consumer and producer surplus for decreasing average cost function.

From the marginal analysis discussed above, a price of P_1 will lead to a maximum of welfare, but the revenues OP_1AQ_1 would be less than total cost -- a loss of P_1C_1BA. However, the utility could employ decreasing block rates, permitting the utility to recover costs, but at the same time offering the consumer the opportunity to purchase marginal units at a price of P_1.

It can be seen therefore that the welfare measure will primarily depend on the price at which the consumer can buy the last units ("marginal price"). At the same time the pricing structure (decreasing block rate, uniform unit rate, etc.) will affect the division of welfare between consumers and producers and also perhaps the other evaluative criteria we are considering.

When actually calculating our welfare measures, it is at least possible that special situations will arise. For example, most decreasing block rates lead to only one point of intersection with the demand curve, as shown by point A in Figure 5-4. Here consumer surplus is the shaded area $D_1FGHJKA$. The corresponding producer surplus is the other shaded area FRSAKJHG. However, the case of multiple or no intersection points could arise, as in Figure 5-5. Of course, when there is only one point of intersection, that point of consumption is chosen by the consumer, since each house will buy additional units as long as the cost to it (price) is less than its willingness to pay (demand). On the other hand, the nonexistence of intersection points (as with demand curves D_1 or D_3 in Figure 5-4) indicates that the rate schedule has been designed incorrectly by the utility companies.

The analysis for increasing block rate (IBR) as shown in Figure 5-6 is similar. The demand function DD intersects the rate at only one point A, which gives the quantity consumed, Q_1. Consumer surplus is DP_2EFA. Total revenue is the area OP_2EFAQ_1. Subtracting the total cost $P_1OQ_1A_1$ from total revenue gives the producer surplus. The shaded area DP_1A_1A is the sum of consumer surplus and producer surplus.

The cases of uniform rates and flat rates are easy enough to analyze but there is no need to discuss them further here.[1]

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[1] In calculating consumer surplus, a problem arises in the case of exponential demand functions such as equations (2) and (4), since for p=0, q is infinite. In such cases, in the calculations reported below, p is set to 5¢/thousand gallons, to provide a finite consumer surplus.

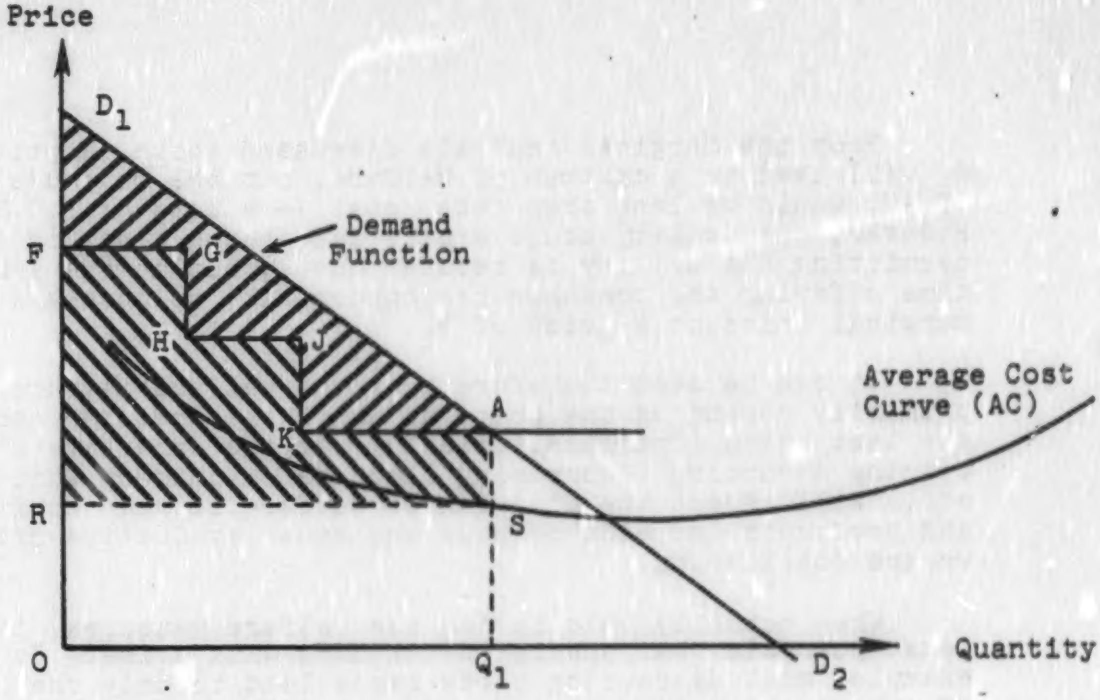

Figure 5-4. This figure illustrates the calculation of social welfare for a decreasing block rate.

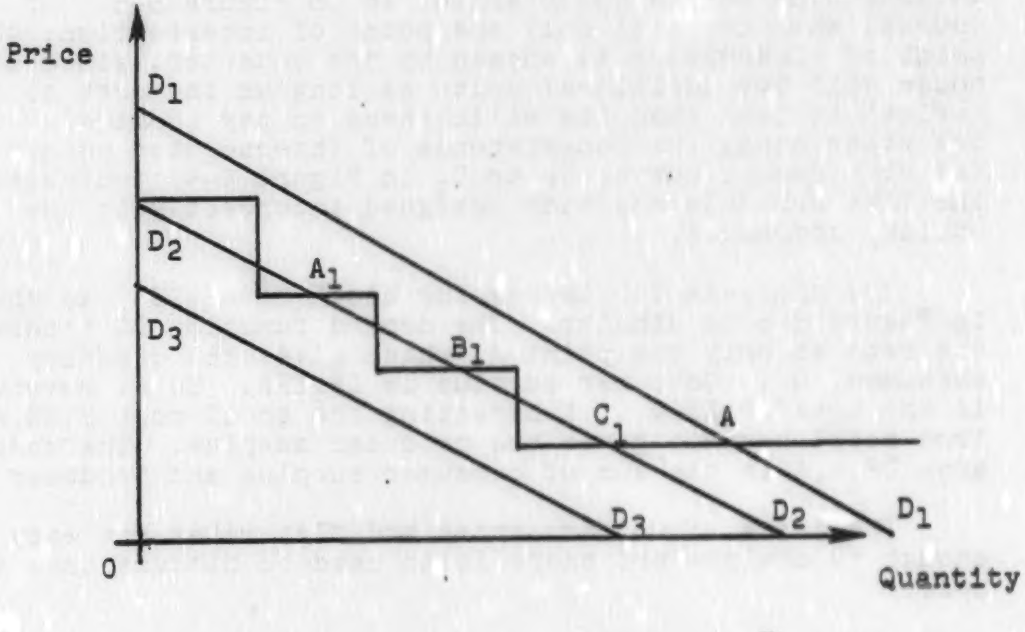

Figure 5-5. This figure shows some special cases of decreasing block rates.

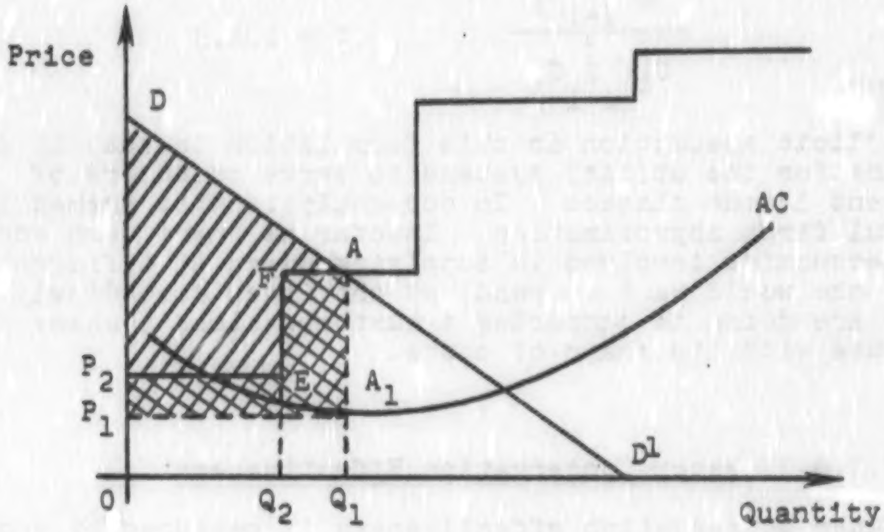
Price
D
A
F
AC
P_2
E
A_1
P_1
D^1
0
Q_2
Q_1
Quantity

Figure 5-6. This figure shows the analysis for an increasing block rate.

5.2.5.2 Discriminatory Effects

The discriminatory effect across income classes for each housing type is measured by the ratio of the share of water consumed by each income class to the share of costs paid by that class. Mathematically, for income class i that pays a cost C_i for quantity Q_i, the ratio is:

$$\frac{Q_i / \sum_{i=1}^{3} Q_i}{C_i / \sum_{i=1}^{3} C_i} \qquad i = 1,2,3 \qquad (23)$$

The implicit assumption in this formulation is that it costs the same for the utility systems to serve customers of different income classes. In our analysis this seemed like a useful first approximation. Insofar as there were economies or diseconomies involved in supplying users at different sizes, one would want to readjust the index accordingly. All we are doing is comparing a customer class's share of water use with its share of costs.

5.2.5.3 Water Conservation Effectiveness

Water conservation effectiveness is measured by comparing the quantity of water consumed for each case. The rate structure that results in the lowest quantity of water consumed is most effective in water conservation. In economic terms of course, the "right" degree of water conservation is that which leads to economic efficiency as previously discussed. However, as alluded to in Section 3.3, we believe our ability to analyse efficiency is sufficiently imperfect as to warrant the use of a distinct criterion in this context.

5.3 Results

This section presents the results of evaluating the costs and benefits of different rate structures. The rate structures considered were decreasing block rates (DBR), increasing block rate (IBR), uniform unit rate (UUR) and flat rates (FR). They were evaluated with respect to the sum of consumer surplus and producer surplus (social welfare), distributional effect across income classes, ability to conserve water, and revenue adequacy.

For each category of rate structure, three different cases of rates were evaluated: high, medium and low. Based on the data from AWWA,[1] Department of Public Works of Wellesley, Massachusetts,[2] Fairfax County Water Authority[3] and Denver Water Board,[4] practical levels and blocks for the rate schedules were chosen to form the case of medium rate schedules. These medium rate schedules were so designed that they all produced approximately the same revenue to the utility companies for their combined water and sewer services (about \$12 - \$13 per household of three, per billing period of two months). The four medium rate schedules were increased 50 percent to form the high rate schedules, or decreased 50 percent to form the low ones. (See Table 5-4)

These three sets of four rate schedules each were evaluated with respect to those criteria previously mentioned, and highlights of the results are presented below. In interpreting these results note that a social welfare of ten dollars does not imply that society will literally gain ten dollars. Instead, the number only indicates that such an outcome is better than a social welfare of less than ten.

In viewing the results of this model it should be noted that firstly, the demand functions are averaged over the year. No attempt has been made to segregate seasonal variations. A more detailed formulation would have to take

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[1] AWWA, Operating Data.

[2] Water rate schedule information from the Department of Public Works, Wellesley, Massachusetts, issued June 26, 1973.

[3] Black & Veatch, Report on Cost of Service and Water Rates, Fees and Charges for Fairfax County Water Authority, Black & Veatch Consulting Engineers, 1974.

[4] Denver Board of Water Commission, 1973 Annual Statistical Report.

TABLE 5-4

RATE STRUCTURES USED IN PRICING ANALYSIS (¢/1000 GALS)

PRICING SCHEME	LOW	MEDIUM	HIGH
IBR			
0-4,000 gallons	25	50	75
4,000-22,000 gallons	35	70	105
>22,000 gallons	45	90	135
DBR			
0-4,000 gallons	58	115	172
4,000-8,000 gallons	33	65	97
>8,000 gallons	23	45	67
UUR			
The whole range of consumption	30	60	90
FR			
The whole range of consumption	$6	$12	$18

this into account, and an analysis of seasonal rate structures would be in order. Second point, this model does use long-run cost curves. This fact essentially assumes that the utility system always runs at the plant size appropriate for a given output. However, most water and wastewater facilities are built rather infrequently so that they are designed for excess capacity in the short run and, as a result, these facilities rarely operate at designed capacities. The results of this model have to be viewed from this perspective. Lastly, as with all models that abstract the real world, the results are only as good as the model. Conclusions and inferences are only valid for the particular set of demand functions, cost functions, and rate structures with their corresponding assumptions. A careful scrutiny of this model would be required prior to the generalization of these results.

5.3.1 Case of Decreasing Average Cost Function

This section highlights the results for the case of decreasing average cost (AC) function. Since these results also hold for other housing types in other regions, only results for single family houses in Region I will be displayed.

The welfare measure (over all consumers in Region I) is shown in Table 5-5, with the rate structures referred to above. The demands for one housing group in Region I are shown in Table 5-6. Demands for all three housing groups in Region I are shown in Table 5-7.

Consider briefly the Flat Rate case. The demands predicted for flat rate users are far larger than the consumption estimated under other pricing structures, and the estimate of welfare is very small. The high total cost of supplying such a large quantity of consumption nearly completely outweighs the total willingness to pay of the consumer.

The main interest centers on the other three rate structures -- DBR, IBR and UUR. These structures, taken at three levels (nine cases in total), lead to a wide variation in welfare. However, the differences can be readily explained in terms of the discussion in Section 5.2.5.1. It was pointed out there that the magnitude of social welfare depends primarily on marginal price (the price in the last block), and not on whether earlier blocks are priced higher or lower (which affects the division of benefits between consumers and producers but not, in the present analysis, the total social welfare).

First, it may be noted that consumption for all of the housing groups in Region I is in the same block of the rate structure for a given rate policy and level (compare Tables 5-4 and 5-7). Hence, consumption in each pricing situation can be plotted against the marginal price to locate a point on the demand curve. Figure 5-7 shows the demand curve for the single-family housing group in Region I (using data from Table 5-6 and 5-4). Thus, even though there are different rate structures considered, each of them contributes some information about the demand curve, by virtue of the fact that only one price block for each policy and level is relevant. Similar demand curves can be formed for the other housing groups.

Next, note that the efficiency measures (for total Region I) associated with each of the points on the demand curve vary in a fairly regular way as one moves along the demand curve. The marginal cost curve is not shown, but one can infer what is occurring. It is apparent that since the maximum of our index of economic efficiency is in the range of 30 cents to 45 cents per 1,000 gallons, the marginal cost curve crosses the demand curve in the same range. At marginal prices considerably above this, it is clear that we suffer efficiency costs (regardless of rate strucure).

The optimal marginal price may be interpolated more precisely in Figure 5-8, which plots the sum of producers and consumers' surplus against marginal price. It appears from this diagram that the most efficient price within this simplified formulation is between 35 cents and 45 cents, perhaps about 40 cents.

In this analysis, one can achieve relatively efficient outcomes with any sort of pricing structure, so long as it is set up to yield marginal prices equal to marginal costs. The major difference among policies lie in their financial implications and their effects on other evaluative criteria. In this particular analysis, we have assumed that average costs are declining and hence that marginal costs are less than

TABLE 5-5

CUMULATIVE SUM OF CONSUMER SURPLUS AND PRODUCER SURPLUS (SOCIAL WELFARE) FOR REGION I OVER ONE YEAR IN MILLIONS OF DOLLARS FOR DECREASING AC FUNCTION

RATE SCHEDULE CASE	INCREASING BLOCK RATE	DECREASING BLOCK RATE	UNIFORM UNIT RATE	FLAT RATE
Low Rate	10,702	9,342	10,282	0.08
Medium Rate	5,292	10,387	7,586	0.08
High Rate	4,169	5,673	4,537	0.08

TABLE 5-6

WATER CONSUMPTION FOR DIFFERENT RATE STRUCTURES FOR DECREASING AC FUNCTION[a]

in liters/household/two months
(gal/household/two months)

RATE SCHEDULE CASE	INCREASING BLOCK RATE	DECREASING BLOCK RATE	UNIFORM UNIT RATE	FLAT RATE
Low Rate	77,441 (20,433)	86,679 (23,662)	81,815 (21,587)	129,360 (34,132)
Medium Rate	57,328 (15,126)	70,384 (18,571)	62,065 (16,376)	129,360 (34,132)
High Rate	43,123 (11,378)	58,700 (15,488)	48,895 (12,901)	129,360 (34,132)

[a] Results are for Region I, single-family houses and income class 2 ($6,000-$15,000/year).

TABLE 5-7

VARIATIONS OF WATER CONSUMPTION AMONG HOUSING TYPES OF REGION I FOR DECREASING AS FUNCTION

WATER CONSUMED
liters/household/two months
(gal/household/two months)

		LOW RATE	MEDIUM RATE	HIGH RATE
INCREASING BLOCK RATE	H_1[a]	77,441 (20,433)	57,328 (15,126)	43,123 (11,378)
	H_2	77,116 (18,764)	53,443 (14,101)	40,201 (10,607)
	H_3	61,618 (16,258)	47,610 (12,562)	35,816 (9,450)
DECREASING BLOCK RATE	H_1	89,679 (23,662)	70,384 (18,571)	58,700 (15,488)
	H_2	81,182 (21,420)	65,082 (17,172)	54,693 (14,431)
	H_3	68,425 (18,054)	57,123 (15,072)	48,679 (12,844)
UNIFORM UNIT RATE	H_1	81,815 (21,587)	62,065 (16,376)	48,895 (12,901)
	H_2	74,765 (19,727)	57,733 (15,233)	45,639 (12,042)
	H_3	64,184 (16,935)	51,233 (13,518)	40,750 (10,752)
FLAT RATE	H_1	129,360 (34,132)	129,360 (34,132)	129,360 (34,132)
	H_2	109,751 (28,958)	109,751 (28,958)	109,751 (28,958)
	H_3	80,306 (21,189)	80,306 (21,189)	80,306 (21,189)

[a] H_1 ~ single-family units
H_2 ~ 2-5 family units
H_3 ~ townhouses and apartment buildings

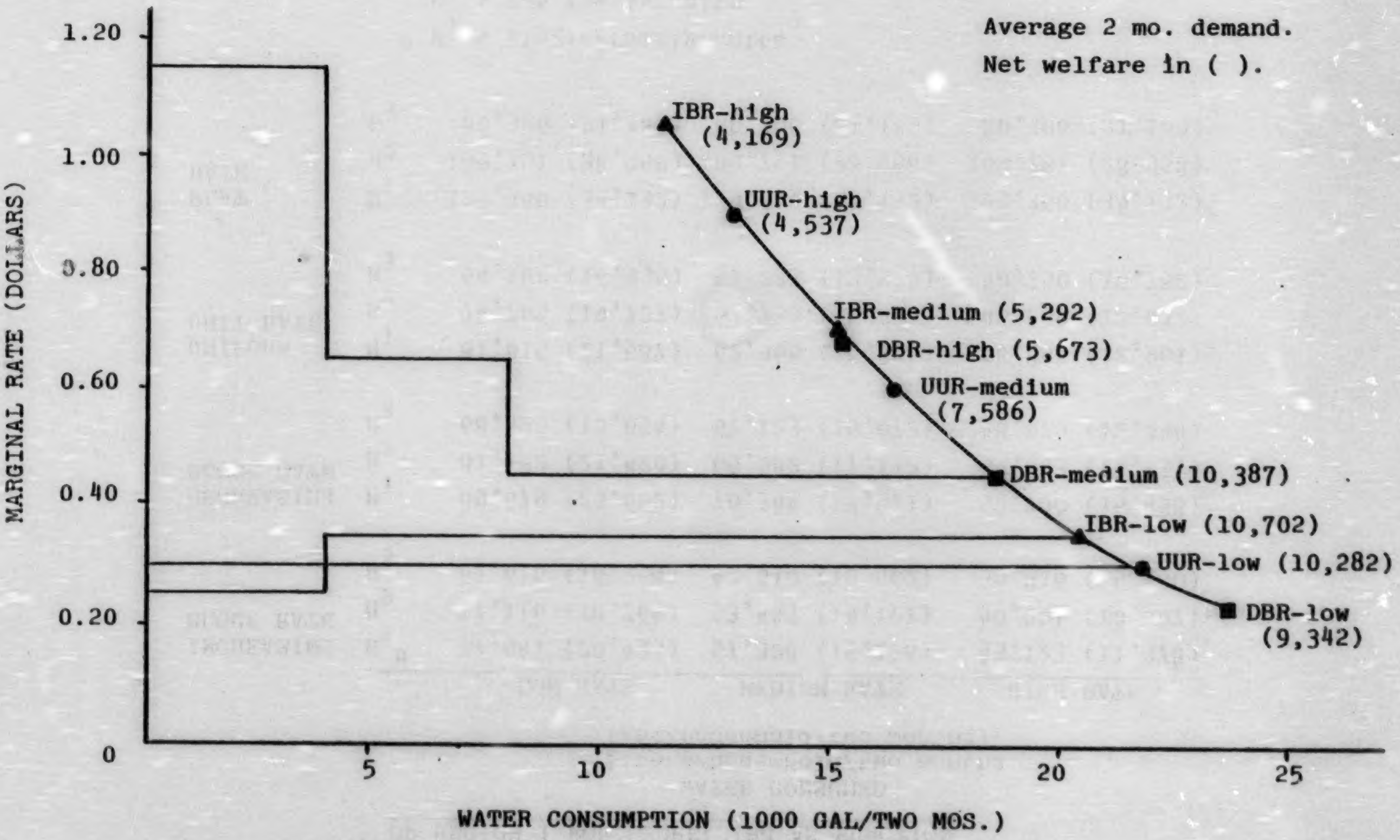

Figure 5-7. This graph shows the demand curve for Region I for single-family housing for decreasing average cost curve.

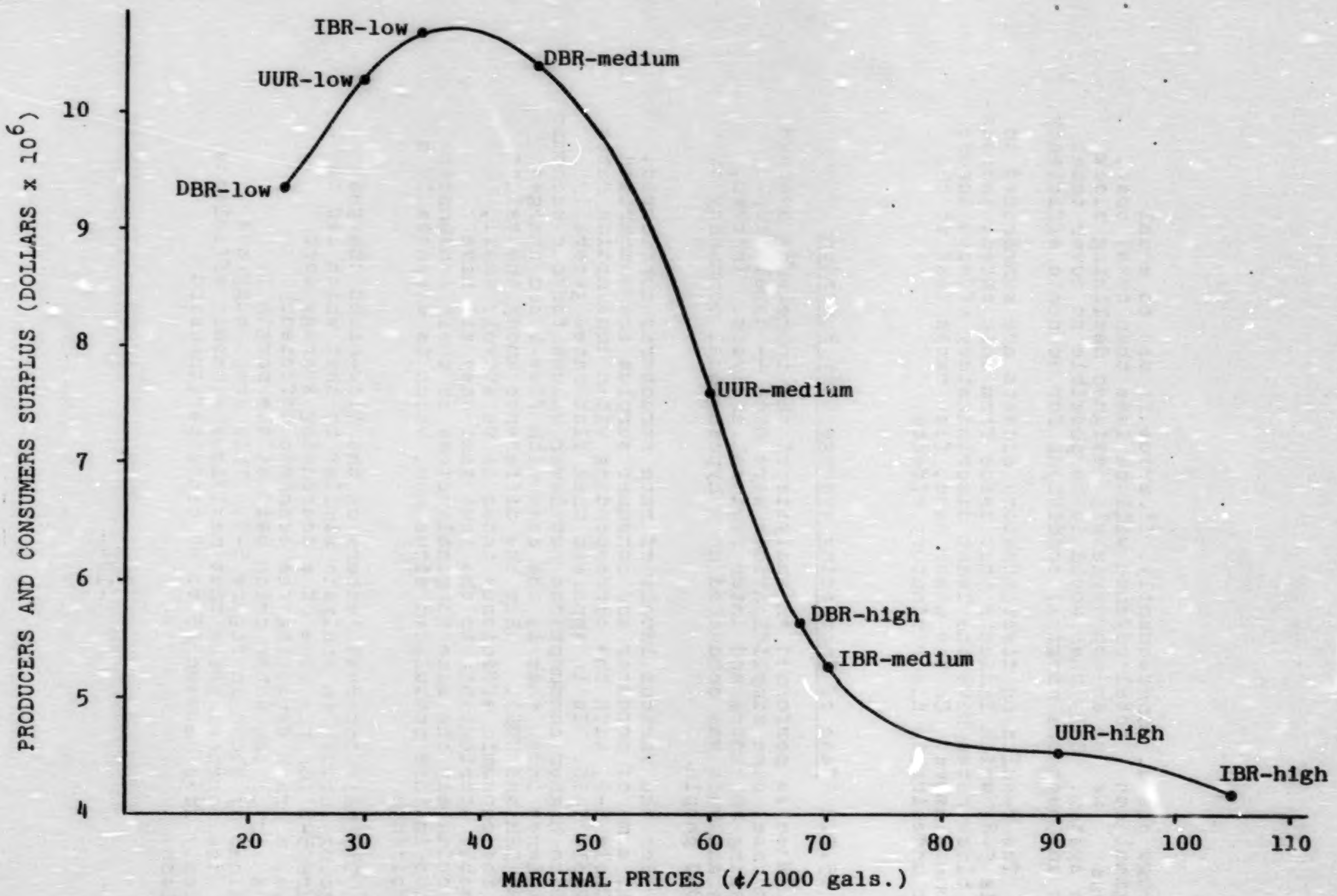

Figure 5-8. This graph shows the producers' plus consumers' surplus in relation to rates at the margin for the decreasing average cost curve. (Table 5-5, rate structures and Figure 5-7.)

average costs. Consequently, if price is set to equal marginal cost, total revenue will be less than total cost, unless we use an appropriately designed declining block rate system. Only then would it be possible to cover total cost and meet the marginal conditions for economic efficiency.

The results on discriminatory effects are summarized in Table 5-8, which indicate that aside from unit rates, increasing block rates have the least discriminatory effects across income classes. On the other hand, flat rates lead to the most undesirable discriminatory effects.

5.3.2 Case of Increasing Average Cost Function

When we performed an analysis of the increasing average cost case, some simplifications were made -- namely suppressing the intra and inter regional analysis. Instead, this analysis was conducted on a hypothetical community of 50,000 people.

For the various levels of rate structures considered, their sums of producer and consumer surplus are summarized in Table 5-9, with the corresponding water consumption rates in Table 5-10. It is apparent that flat rates generally lead to higher consumptions but lower values for our economic efficiency index than is the case with flow-based charges (IBR, DBR and UUR). But the difference among the values for the economic efficiency index is relatively small, probably attributable to the fact that they all have approximately the same marginal prices at their consumption points in this postulated situation, which is essentially a coincidence

The main interest centers on the flow-based charges. By going through an analysis similar to that which led to Figure 5-8 for the case of a decreasing average cost curve, a graph depicting the economic efficiency index versus the water price paid at the margin is obtained as shown in Figure 5-9. This graph suggests that the marginal price that maximizes economic efficiency probably lies between 25 to 40 cents per thousand gallons.

Table 5-10 shows that flat rates, here as is the case with decreasing average costs, do encourage more water consumption than other rate structures. Similarly, Table 5-11 which displays discriminatory effects, shows that in general the same observations as for the decreasing AC function case also apply here.

5.4 Conclusions

In order to use pricing policies to regulate water consumption and yet achieve economic efficiency, a joint analysis of the rate structure, average cost functions and demand functions is in order. The model employed here is of some interest due to the fact that it utilizes cost and demand functions of the complexity found in professional studies. There are some important limitations of the model which are discussed below, but for the given model it is possible to offer the following conclusions:

Based on the cost and demand functions used here, flat rate policies appear to be significantly less efficient than those policies employing flow-based charges.

Among the rate structures employing flow-based charges (UUR, DBR, IBR), it was shown that with the present cost functions, any of these policies could lead to economically efficient outcomes in the single case considered since the important factor in such results is the unit price at the margin of consumption. In the one-period analysis considered here (i.e., no consideration of seasons), any one of the policies could produce prices at the margin equal to incremental cost.

In such a situation, the choice among rate structures would appear to rest on the nature of financial constraints and other goals. For example, in a situation of declining average cost, a declining block rate will permit the use of marginal cost prices, but allow the utility to recover its total costs. Similarly, in a situation of increasing average costs, an increasing block rate will permit the utility to use marginal cost pricing without surpassing the profit limitations often placed on utilities.

The conclusions stated here are ones that have been stated before on the basis of theoretical analyses; the present analysis is useful in showing that a fairly complex model can be manipulated to show the same results, and, with calculation of a rather small number of alternatives, zero in on a rather narrow range around the optimal price. As an exploratory effort, however, the analysis excluded a number of factors that are important to utilities, such as:

1. seasonal demands;
2. more explicit distinction between water and sewer prices;
3. the fact that there may be components of a system which have plenty of capacity (collectors) for which a different pricing policy may be appropriate than for components of a system which typically are operated nearer to capacity.

TABLE 5-8

DISCRIMINATORY EFFECTS ACROSS INCOME CLASSES FOR SINGLE-FAMILY HOMES IN REGION I FOR DECREASING AC FUNCTION

	INCOME CLASS 1[a]			INCOME CLASS 2[b]			INCOME CLASS 3[c]		
RATE STRUCTURE	LOW RATE	MEDIUM RATE	HIGH RATE	LOW RATE	MEDIUM RATE	HIGH RATE	LOW RATE	MEDIUM RATE	HIGH RATE
INCREASING BLOCK RATE	1.0207	1.0172	1.0297	1.0135	1.0060	1.0100	0.9744	0.9849	0.9766
DECREASING BLOCK RATE	0.9571	0.9458	0.9328	0.9851	0.9804	0.9754	1.0445	1.0570	1.0704
UNIFORM UNIT RATE	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FLAT RATE	0.7167	0.7167	0.7167	0.8874	0.8874	0.8874	1.3959	1.3959	1.3959

[a] Income Class 1 ∼ income of <$6,000/year
[b] Income Class 2 ∼ income of $6,000-$15,000/year
[c] Income Class 3 ∼ income of >$15,000/year

TABLE 5-9

PRODUCER PLUS CONSUMER SURPLUS FOR DIFFERENT RATE STRUCTURES IN MILLIONS OF DOLLARS FOR ONE YEAR FOR INCREASING AC FUNCTION

	INCREASING BLOCK RATE	DECREASING BLOCK RATE	UNIFORM UNIT RATE	FLAT RATE
Low Rate	11.5	11.6	11.7	6.99
Medium Rate	7.9	10.9	8.3	6.99
High Rate	6.7	8.0	7.2	6.99

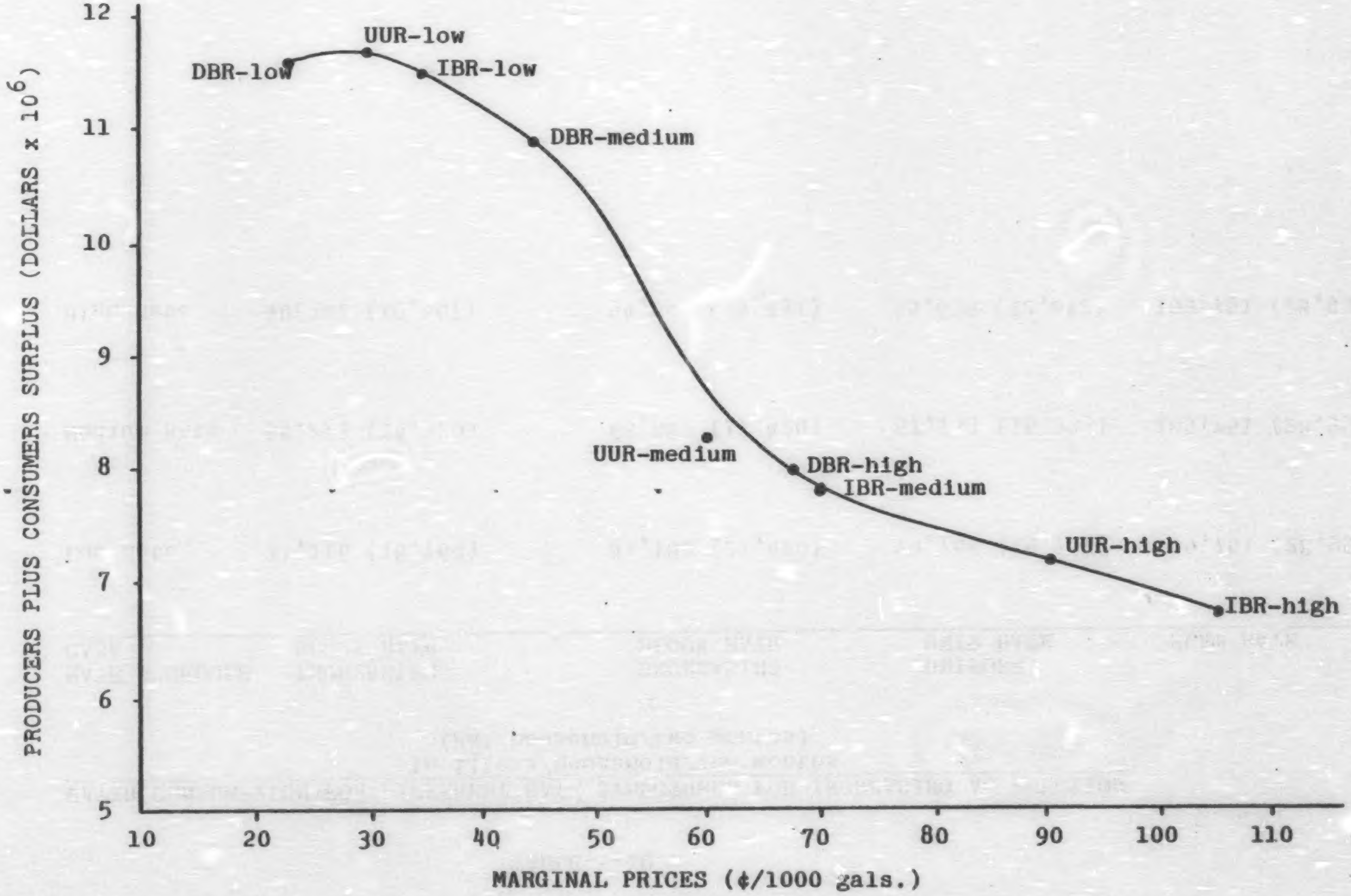

Figure 5-9. This figure shows the relationship between producers' plus consumers' surplus and marginal prices for increasing AC curve.

TABLE 5-10

WATER CONSUMPTION FOR DIFFERENT RATE STRUCTURES FOR INCREASING AC FUNCTION

in liters/household/two months
(gal/household/two months)

RATE SCHEDULE CASE	INCREASING BLOCK RATE	DECREASING BLOCK RATE	UNIFORM UNIT RATE	FLAT RATE
Low Rate	71,116 (18,764)	81,182 (21,420)	74,765 (19,727)	109,751 (28,958)
Medium Rate	54,273 (14,320)	65,082 (17,420)	57,733 (15,233)	109,751 (28,958)
High Rate	40,201 (10,607)	54,693 (14,431)	45,639 (12,042)	109,751 (28,958)

TABLE 5-11

DISCRIMINATORY EFFECTS ACROSS INCOME CLASSES FOR INCREASING AC FUNCTION

RATE STRUCTURE	INCOME CLASS 1[a]			INCOME CLASS 2[b]			INCOME CLASS 3[c]		
	LOW RATE	MEDIUM RATE	HIGH RATE	LOW RATE	MEDIUM RATE	HIGH RATE	LOW RATE	MEDIUM REATE	HIGH RATE
INCREASING BLOCK RATE	1.0127	1.0217	1.0325	1.0052	1.0076	1.0111	0.9865	0.9809	0.9746
DECREASING BLOCK RATE	0.9551	0.9437	0.9302	0.9840	0.9793	0.9740	1.0474	1.0600	1.0740
UNIFORM UNIT RATE	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
FLAT RATE	0.7275	0.7275	0.7275	0.8910	0.8910	0.8910	1.3814	1.3814	1.3814

[a] Income Class 1 ~ income of <$6,000/year
[b] Income Class 2 ~ income of $6,000-$15,000/year
[c] Income Class 3 ~ income of >$15,000/year

CHAPTER SIX

COST-EFFECTIVENESS OF WATER-SAVING DEVICES

This chapter contains a description of the analysis of cost savings associated with installing water-saving devices. The analysis is performed through the mathematical model entitled Engineering Economy Analysis Model (EEAM), which is described in Section 6.1. Cost savings are broken down into three major components: household savings, savings to the water utilities, and savings to the wastewater industries. Section 6.2 presents the mathematical modeling of the components of this model. This model is similar to the Policy Analysis Model in the classifications of climatic regions and income classes, and in the cost functions for the water and wastewater industries. Section 6.3 is a discussion of the assumptions made. Section 6.4 presents the results of computer runs, and conclusions follow in Section 6.5.

6.1 General Description

This section is a discussion of the mechanics of EEAM, its inputs and outputs. This computer model calculates the national and regional cost savings that result from the installation of water-saving devices. Cost savings are broken down into three major components: household savings, savings to water utilities, and savings to wastewater industries. Household savings are computed from the following calculation: reductions in water bills and sewer service charges, less the net annualized cost of devices giving credits for salvage values of the devices, plus the savings in fuel costs for hot water. Savings to water utilities are composed of reductions in amortized costs of capital outlays for capacity expansions and annual operating and maintenance costs, less the reductions in revenues derived from water bills. Similarly, savings to wastewater industries are made up of reductions in amortized costs of capital outlays and annual operating and maintenance costs, less the loss of revenues derived from the sewer service bills.

The computer model considers three different strategies of installing the water-saving devices. These strategies are:

1. S_1 - Replace water-using appliances immediately with water-saving devices;

2. S_2 - Replace water-using appliances with water-saving ones only when the former wears out.

3. S_3 - Replace with the original type of appliances when the current ones become worn out.

Seven water-saving devices plus the reuse of wastewater for toilet flushing are considered for the first two strategies. The last strategy is the control case.

The water-saving devices considered in this analysis are some of the more common appliances cited in the field, including faucet aerators, thermostatic mixing valves, flow-limiting shower heads, dual cycle water closets, shallow trap water closets, vacuum flush toilets and toilet inserts. Also considered is the option of recycling wastewater from bathing, cleaning and laundry uses for toilet flushing. Detailed descriptions of these devices have been presented in Section 3.2, but a brief description of these devices and options is provided here with a summary of the relevant technical data for these devices given in Table 6-1, which serves as part of the input data base for this computer model.

Faucet aerators and flow-limiting shower heads are water-saving devices that limit the flows from faucets or shower heads. Thermostatic mixing valves are electronic temperature control devices that regulate the temperature of water flowing from the tap. Dual cycle water closets have the ability to provide for two types of flush: one for liquid waste and the other for solid waste, using a different quantity of water for each operation. Water-saving closets are ordinary water closets with smaller bowls and tanks for each flush. Vacuum flush toilets utilize vacuum suction force to dispose of wastes. Toilet inserts are objects placed inside the tanks to reduce the water requirements for each flush. It should be noted, that some of these figures, such as those for toilet inserts, are composite; they do not always represent actual commercial products. Moreover, the mentioning of a product by its brand name does not imply its endorsement.

TABLE 6-1

INPUT DATA BASE FOR WATER-SAVING DEVICES

Device	WATER SAVED/USE IN LITERS (IN GALLONS)	CAPITAL COST OF DEVICE, INC. PRICE & INSTALL. ($)	EXPECTED LIFE OF SERVICE (YEARS)
faucet aerator	4.6 (1.2)	2.8	2.0
thermostatic mixing valve	31.5 (8.3)	500.0	50.0
flow-limiting shower heads	56.9 (15.0)	18.0	10.0
dual cycle toilet	75.8 (20.0)	57.0	50.0
shallow trap water closet	41.7 (11.0)	53.0	50.0
vacuum flush toilet	91.0 (24.0)	1300.0	15.0
toilet insert	49.3 (13.0)	4.5	10.0
recycle wastewater for toilet flushing	94.8 (25.0)	500.0	13.0
standard toilet	0.0 (0.0)	50.0	50.0
standard shower head	0.0 (0.0)	10.7	10.0
standard mixing valve	0.0 (0.0)	20.0	50.0

A description of the flow chart of Figure 6-1 will show how this model works. Appropriate data on water use patterns, water-saving devices, their water savings and costs, water and service costs, and energy costs are read in. A region and an income class are picked. The rationale behind the segregation into income classes and geographical regions is to take into account the variations in water consumption among income classes in various areas. The geographical classification also attempts to capture the cost variations in providing water and sewer services. Then the subprogram QUAN will be called to calculate the initial quantities of water consumed and wastewater generated. Subprogram WASAV will next be called to determine the water saved using those water-saving devices. Then QUAN is used to compute the revised quantities of water consumption and wastewater generation upon the use of water-saving devices.

Following further the flow chart of Figure 6-1, we begin the analysis of the savings associated with those devices. First, subprogram SDCAP is used to calculate the replacement cost using strategy S_3. This serves as the basis for comparison with the other strategies. Subprograms COCA and HHCOS will be called to calculate the costs of providing water and sewer services as well as the water and sewer bills to households, including energy heating costs. Then the computations in subprograms SDCAP, COCA and HHCOS are repeated using the replacement strategy (S_1 or S_2) under consideration. Next, cost savings to water industries, sewer industries and households are calculated and then accumulated for the whole time period. This sequence of computations is repeated for all devices, income classes and region to obtain regional and national cost savings for a given replacement strategy. Moreover, the unit rates of water and sewer services have been varied to investigate the relative cost savings of various water-saving devices.

6.2 Mathematical Model

This section presents the theory behind the formulation of this model. Since some of the rationale behind the Policy Analysis Model (PAM) can be carried over, discussions for some sections will be brief.

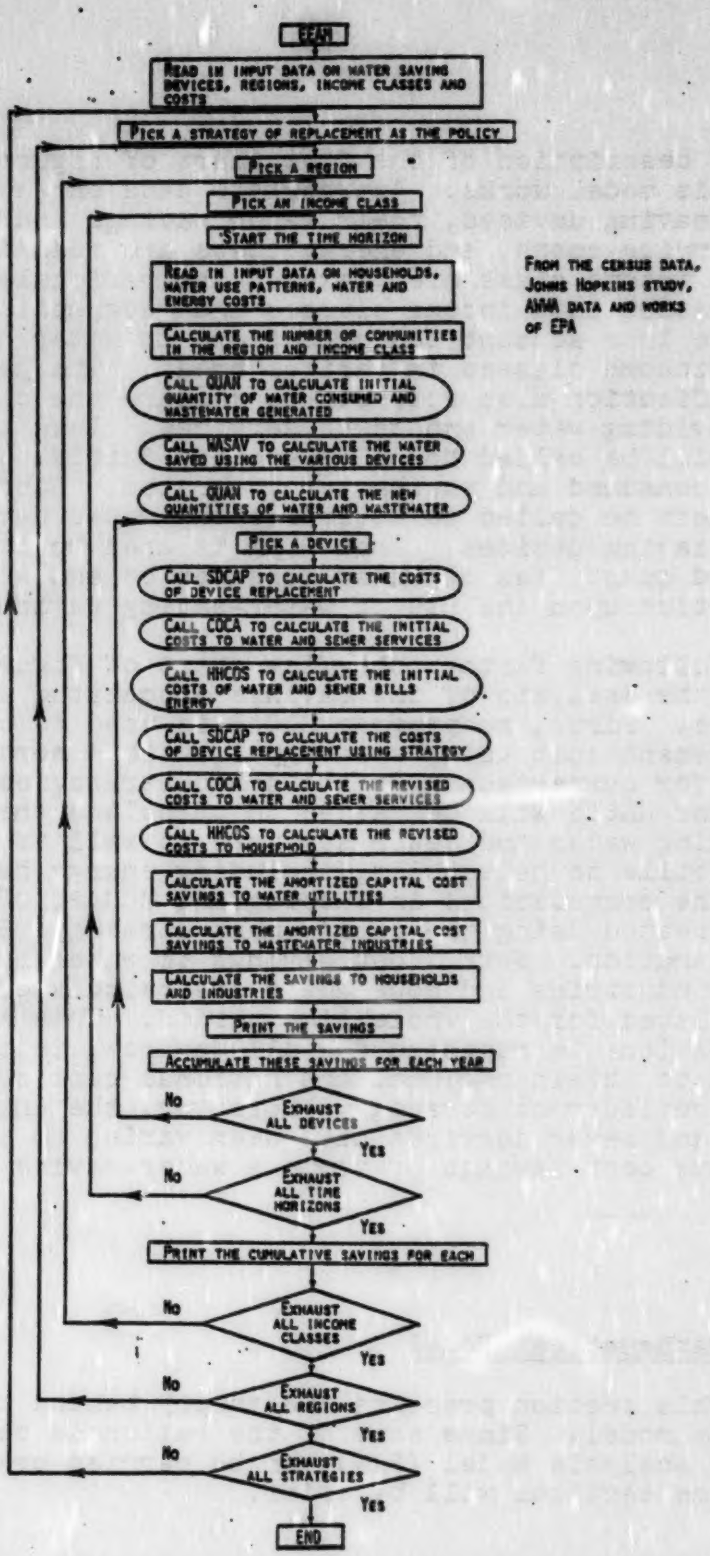
EEAM
READ IN INPUT DATA ON WATER SAVING DEVICES, REGIONS, INCOME CLASSES AND COSTS
PICK A STRATEGY OF REPLACEMENT AS THE POLICY
PICK A REGION
PICK AN INCOME CLASS
START THE TIME HORIZON
READ IN INPUT DATA ON HOUSEHOLDS, WATER USE PATTERNS, WATER AND ENERGY COSTS
FROM THE CENSUS DATA, JOHNS HOPKINS STUDY, AWWA DATA AND WORKS OF EPA
CALCULATE THE NUMBER OF COMMUNITIES IN THE REGION AND INCOME CLASS
CALL QUAN TO CALCULATE INITIAL QUANTITY OF WATER CONSUMED AND WASTEWATER GENERATED
CALL WASAV TO CALCULATE THE WATER SAVED USING THE VARIOUS DEVICES
CALL QUAN TO CALCULATE THE NEW QUANTITIES OF WATER AND WASTEWATER
PICK A DEVICE
CALL SDCAP TO CALCULATE THE COSTS OF DEVICE REPLACEMENT
CALL COCA TO CALCULATE THE INITIAL COSTS TO WATER AND SEWER SERVICES
CALL HHCOS TO CALCULATE THE INITIAL COSTS OF WATER AND SEWER BILLS ENERGY
CALL SDCAP TO CALCULATE THE COSTS OF DEVICE REPLACEMENT USING STRATEGY
CALL COCA TO CALCULATE THE REVISED COSTS TO WATER AND SEWER SERVICES
CALL HHCOS TO CALCULATE THE REVISED COSTS TO HOUSEHOLD
CALCULATE THE AMORTIZED CAPITAL COST SAVINGS TO WATER UTILITIES
CALCULATE THE AMORTIZED CAPITAL COST SAVINGS TO WASTEWATER INDUSTRIES
CALCULATE THE SAVINGS TO HOUSEHOLDS AND INDUSTRIES
PRINT THE SAVINGS
ACCUMULATE THESE SAVINGS FOR EACH YEAR
NO
EXHAUST ALL DEVICES
YES
NO
EXHAUST ALL TIME HORIZONS
YES
PRINT THE CUMULATIVE SAVINGS FOR EACH
NO
EXHAUST ALL INCOME CLASSES
YES
NO
EXHAUST ALL REGIONS
YES
NO
EXHAUST ALL STRATEGIES
YES
END

Figure 6-1 Shows the flow chart of the engineering economy analysis model (EEAM) to evaluate the cost-effectiveness of water saving devices.

6.2.1 Regional Classification

As in the PAM, this model divides the nation into seven regions to capture the regional variations in water use patterns and costs of water and sewer services. The classification is identical to that of PAM and it has been presented in Table 5-1.

6.2.2 Water Use Patterns

For this model, a detailed knowledge of the quantity of water for various water use categories is needed since the water-saving devices change the quantity of water for some water use categories. These water use categories[1] include bathing, toilet flushing, laundry, kitchen and drinking, cleaning, sprinkling and car washing. Similarly, detailed knowledge of the quantity of wastewater generated is needed. It is assumed that all water uses except sprinkling and car washing lead directly to sewer flow. Wastewater from sprinkling and car washing is assumed to percolate into groundwater resources or flow into separate storm sewers. It does not contribute toward any flow in the municipal sewers.

6.2.3 Water Supply Cost Functions

The model for water costs is identical to that for the PAM. For more detailed discussion, refer to Section 5.2.3 of this report.

6.2.4 Sewer Service Cost Functions

The model for sewer service costs is also identical to that for PAM, which is described in Section 5.2.4 of this report.

6.2.5 Water and Sewer Service Rates (Utility Rates)

For this model, the rates used are taken as the average price paid per thousand gallons of water consumed and the average sewer charge per thousand gallons of wastewater going into municipal sewers. Throughout this report the water and the sewer rates are collectively termed as utility rates. Since these rates vary regionally, the unit price of water and sewer services will also change accordingly. This, again, points out the need for geographical classification in this model.

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[1] A detailed discussion of these water use patterns is provided in Chapter Three.

6.3 General Assumptions

In addition to those assumptions inherent in the components of this model, the following assumptions are also made:

1. Each region is made up of communities which have a population of 50,000. Varying numbers of such communities make up the appropriate population for each region. The rationale behind such an assumption is to ensure that cost functions stay within their valid range of capacity. Inputting the total national water consumption into these design cost functions would not give valid cost estimates because the water consumption quantity would exceed such a range.

2. In spite of the variations within a region in characteristics of water use patterns, and water and sewer service costs, such parameters are assumed to remain unchanged within each of the seven regions of this model. This assumption should simplify the computations considerably.

3. The three strategies considered are to be applied throughout the nation.

4. Cost savings are cumulated over a 10-year period. Total savings over the period are expressed in the tables in terms of present value at the beginning of the period (interest rate = 7%). Salvage values for devices remaining at the end of the period are calculated on a straightlene basis. For the immediate replacement strategy, the old devices are assumed to have a salvage value of half of their initial worth.

5. The housing stock is assumed to grow at the rate of 1% per year. Both for existing stocks of devices and for devices installed during any of the 10 years of the calculation period, if the life of a device is N years, it is assumed that 1/N of the devices are retired in each subsequent year until the stock is zero.

6. To investigate the sensitivity of these strategies to the unit price of water and sewer services,

the model is run with three different utility rates: (a) high rate of $10.00/thousand gallons; (b) medium rate of $1.00/thousand gallons; and (c) low rate of $0.10/thousand gallons. Such rates include both water and sewer services.

6.4 Results

This section presents the results of evaluating the cost savings of installing water-saving devices using different replacement strategies. The basis for comparison is the strategy (S_3) of replacing the current devices with similar devices when the existing devices are worn out. The monetary savings are differences between values associated with a strategy under consideration over the 10 year horizon and the corresponding values for the strategy (S_3) for comparison. Positive values indicate savings relative to strategy S_3; negative ones indicate a new device is more costly. The two strategies considered are labeled S_1, which is to replace the current devices immediately with water-saving devices, and S_2, which is to replace the current devices with water-saving devices when the current ones are worn out. The water-saving devices or options considered are as follows:

- faucet aerators
- thermostatic mixing valves
- flow-limiting shower heads
- dual cycle water closet
- shallow trap water closet
- vacuum flush toilet
- toilet insert
- recycling of waste water from bathing, cleaning and laundry uses for toilet flushing

Highlights of results are presented in the following:

1. Table 6-2 shows the total national cost savings for the strategy (S_1) of replacing current devices with water-saving devices immediately and the strategy (S_2) of replacing current devices with water-saving devices only when the current ones are worn out. These savings are summed over a period of 10 years. The results indicate that

TABLE 6-2

TOTAL NATIONAL SAVINGS FOR DIFFERENT STRATEGIES OF REPLACEMENT FOR TEN YEAR PERIOD

DEVICE	STRATEGY S_1[a] in Millions of Dollars	STRATEGY S_2[b] in Millions of Dollars
Faucet aerators	-2,121	-266
Thermostatic mixing valves	-17,930	-4,258
Flow-limiting shower heads	8,167	2,366
Dual cycle water closet	9,048	1,924
Shallow trap water closet	3,478	991
Vacuum Flush toilet	-74,500	-17,748
Toilet Insert	6,414	1,618
Recycling wastewater for flushing	-15,359	-5,037

[a] S_1 strategy of replacing immediately with water-saving devices

[b] S_2 strategy of replacing with water-saving devices when the current ones are worn

flow-limiting shower heads, dual cycle water closets, shallow trap water closets and toilet inserts all offer net national cost savings. In this case, strategy S_1 is invariably better than S_2, because the savings in capacity expansions of water and wastewater industries are sufficient to compensate for the annual cost of purchasing and installing the water-saving devices. However, if devices that have higher initial costs or that save relatively small amounts of water were used, negative national cost savings result, indicating that the nation would have to pay more if S_1 or S_2 were used than if S_3 were used. Such devices include thermostatic mixing valves, vacuum flush toilets, faucet aerators and recycling wastewater for toilet flushing.

2. Household savings for the two strategies (S_1 and S_2) and the three utility rate cases (low, medium and high) are tabulated in Tables 6-3 and 6-4. These results indicate that very high utility rates can render all devices cost-effective; the savings in utility bills are sufficiently large to compensate for new device costs in the high utility rate case. If the use of a device leads to net household cost savings, the strategy of immediate replacement (S_1) is preferred to the strategy of replacement only when the current devices are worn out (S_2). On the other hand, S_2 is preferred to S_1 if the use of a device does not lead to household cost savings.

3. For the toilet-related devices, toilet inserts are generally superior with respect to household cost savings for the usual range of utility rates (low and medium cases). But at high utility rates, dual cycle closets and the option of recycling wastewater for toilet flushing offer more household cost savings than toilet inserts.

4. Faucet aerators and thermostatic mixing valves do not offer any household cost savings except when the utility rates become very high.

5. Flow-limiting shower heads offer household cost savings for all three utility rate cases, thus indicating that water-saving devices that conserve water use for showers are worth considering.

TABLE 6-3

TOTAL HOUSEHOLD SAVINGS[a] FOR STRATEGY S_1[b] IN MILLIONS OF DOLLARS FOR TEN YEARS FOR DIFFERENT UTILITY RATES

DEVICES	LOW RATE[c]	MEDIUM RATE[d]	HIGH RATE[e]
Faucet Aerators	-2,718	-1,982	5,375
Thermostatic Mixing Valves	-21,977	-17,025	32,499
Flow-limiting Shower Heads	845	9,730	98,575
Dual Cycle Water CLoset	-934	11,095	131,380
Shallow Trap Water Closet	-2,123	4,703	72,963
Vacuum Flush Toilet	-86,500	-72,110	72,286
Toilet Insert	107	7,780	84,513
Recycling of Waste-water for Toilet Flushing	-32,081	-12,332	185,150

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[a] Rounded off to the nearest million

[b] S_1 is the strategy of immediate replacement with water-saving devices

[c] $0.10/thousand gallons

[d] $1.00/thousand gallons

[e] $10.0/thousand gallons

TABLE 6-4

TOTAL HOUSEHOLD SAVINGS[a] FOR STRATEGY S_2[b] IN MILLIONS OF DOLLARS FOR TEN YEARS FOR DIFFERENT UTILITY RATES

DEVICES	LOW RATE[c]	MEDIUM RATE[d]	HIGH RATE[e]
Faucet Aerators	-369	-242	1,032
Thermostatic Mixing Valves	-4,952	-4,094	4,478
Flow-limiting Shower Heads	202	2,862	29,461
Dual Cycle Water Closet	230	2,312	23,134
Shallow Trap Water Closet	34	1,216	13,031
Vacuum Flush Toilet	-19,786	-17,287	7,707
Toilet Insert	541	1,870	15,152
Recycling of Wastewater for Toilet Flushing	-7,806	-4,428	29,349

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[a] Rounded off to the nearest million

[b] S_1 is the strategy of immediate replacement with water-saving devices

[c] \$0.10/thousand gallons

[d] \$1.00/thousand gallons

[e] \$10.0/thousand gallons

There are two qualifications pertaining to these results. Firstly, these results provide only an aggregate view of the real world situation; they are not necessarily applicable to all local circumstances. Consequently, these results should be viewed with the perspective that they are general indications of the expected cost savings, which may vary according to the particular conditions of the local regions. Secondly, the model does not take stochasticity into account, which suggests that these results may not have taken all factors into consideration. After all, no variant is supposed to be deterministic, so that these results are merely the average behavior of a system.

6.5 Conclusions

1. Since flow-limiting shower heads, dual cycle closets, shallow trap closets and toilet inserts all offer net national cost savings, their installations should be encouraged to conserve water and subsequently reduce household wastewater flows.
2. To conserve water for toilet flushing, the devices considered are listed as follows in decreasing order of preference: dual cycle water closets, toilet inserts, shallow trap water closets, recycling wastewater for flushing, and vacuum flush toilets.
3. If the use of a water-saving device leads to net cost savings, its immediate installation is encouraged. On the other hand, if the use of the device incurs negative cost savings, its installation should not be encouraged. Instead, the use of the original type of devices should be continued. Of course, this conclusion assumes that the utility rate is within its plausibility range (up to $1.00/thousand gallons); otherwise, a high enough utility rate will cause all devices to be cost-effective This result agrees with that of Howe et al.[1]

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[1] C.W. Howe et al., Future Water Demands: The Impact of Technological Change, Public Policies, and Changing Market Conditions on the Water Use Patterns of Selected Sectors of the United States Economy: 1970-1990 (Washington, D.C.: Resources For the Future, 1971).

Again, it should be noted that these conclusions should be viewed with a realization of those qualifications stated at the end of Section 6.4. Moreover, the costs of installing devices are for retrofitting, so that this model overestimates the costs for new housing stock. This leads to an underestimation of savings. However, since the housing stock only increases about 1 percent each year, the error introduced is small, especially in view of the short time horizon of interest. Correcting for this error term would lead to larger cost savings, rendering the results even more attractive.

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APPENDIX A

RELATIONSHIP BETWEEN WASTE CONCENTRATION AND TREATMENT EFFICIENCY

This appendix presents the results of an investigation of the effect of increased waste concentration on waste treatment efficiency. The materials of this appendix are compiled from three major sources: Lawrence[1], Middleton & Lawrence[2] and Metcalf & Eddy[3]. The main purpose of this appendix is to determine qualitatively if there would be any efficiency improvement in unit treatment processes due to waste concentration increases caused by wastewater flow reduction. Three major categories of unit treatment processes are investigated: primary, secondary and advanced waste treatment (AWT) processes. Only results for the former two categories are reported; advanced waste treatment usually has such low influent concentrations that waste concentration variations in the influents of primary processes do not affect the efficiency of AWT significantly.

There are two major sections in this appendix. The first concentrated on the primary clarification process, and the second on secondary biological treatment processes. Possible cost savings will be alluded to when appropriate.

A.1 Primary Clarification Process

The primary treatment process under consideration is coagulation or flocculation followed by sedimentation. First various factors that affect this process are given, and then the effect of flow reduction is discussed.

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[1] A.W. Lawrence, "Water Pollution Control Technology: Capabilities and Cost", prepared as discussion paper for Task Force on Liquid Wastes, Committee for Economic Development (Washington, D.C., October 1972).

[2] A.C. Middleton and A.W. Lawrence, "Cost Optimization of Activated Sludge Wastewater Treatment Systems:, EPM Technical Report No. 73-1, (August 1973).

[3] Metcalf & Eddy, Inc. Wastewater Engineering, (New York: McGraw-Hill Book Company, 1972).

A.1.1 Factors Affecting Clarification Processes

Many interacting factors affect the performance of clarification processes. The interaction of all these factors is too complex to be modeled mathematically. According to the American Society of Civil Engineers, et al., there is no encompassing mathematical formula for such processes. However, some of these factors will be examined more closely in the following paragraphs.

The formation of flocs for settling is determined by such factors as: the number of particle contacts, size, density and fragility of flocs, pH of the solution, surface charge and zeta potentials. If larger flocs are formed more easily, then they can settle out more quickly, thus improving the efficiency of this process.

Other factors include the density of solids, contact time, size and shape of particles, relative motion of particles, the hydraulic properties of the tank and the number of basins in series. According to Fair and Geyer,[2] for given surface loading Q/A (where Q is the flow rate out of the tank and A is the surface area of the clarifier), and a number of basins in series (equal to n), the outflow number of particles y is related to the inflow number of particles y_o by the following;

$$\frac{y}{y_o} = 1 - \left[1 + \left(\frac{\nu_o}{Q/A}\right)^n\right]^{-n} \qquad \text{(A-1)}$$

ν_o being the velocity of particles that fall through the full depth of the settling zone during the detention time. Another functional relationship relates the terminal velocity to the various parameters of this process as follows:

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[1] American Society of Civil Engineers, et al, Water Treatment Plant Design (New York: American Water Works Association, Inc., 1969), chap. 6.

[2] G.M. Fair & J.C. Geyer, Water Supply Wastewater Disposal. (New York: John Wiley & Son, Inc. 1954), chap. 22.

$$\nu = \left[\frac{4dg(s_s - s_\ell)}{3Cs_\ell}\right]^{1/2} \qquad \text{(A-2)}$$

where ν = terminal velocity of particle
d = diameter of particle
g = gravitational acceleration
s_s = specific gravity of solid
s_ℓ = specific gravity of water
C = drag coefficient

A.1.2 Effects of Flow Reduction

Given the interaction of those factors mentioned in the last section, effects of flow reduction can be qualitatively analyzed. Eqn. (A-2), shows that the terminal velocity depends on the diameter of particles. Actually, this dependence can be displayed more vividly by substituting the following:

$$s_s - s_\ell = kd^{-0.7} \qquad \text{(A-3)}$$

into Eqn. (A-2), so that the terminal velocity depends on diameter (d) as follows:

$$\nu = \left[\frac{4gkd^{0.3}}{3Cs_\ell}\right]^{1/2} \qquad \text{(A-4)}$$

where k is a constant. If waste concentration increases as a result of flow reduction, there will be more floc contacts, so that larger and heavier flocs can be formed. This phenomenon leads to larger diameters (d), thus increasing the terminal velocity. This means that it takes a shorter contact time for the particles to settle, resulting in a shorter operating time for the same removal efficiency. Consequently, some cost savings would be associated with primary settling, bearing in mind that the analysis has been conducted for an ideal settling basin only.

A.2 Secondary Processes

A.2.1 Functional Relationships of Parameters of Biological Treatment Processes

There are two operational parameters widely applied in the design and operation of biological treatment systems. The first parameter is the process loading factor (U) which is also known as either the:

1. substrate removal rate
2. specific utilization, or
3. food to microorganism ratio

and is defined by:

$$U = \frac{dF/dt}{X} \text{ or } \frac{(\Delta f/\Delta t)_t}{X_t} \qquad \text{(A-5)}$$

where, dF/dt is the substrate utilization rate, and where X is the reactor microorganism concentration. This parameter indicates the mass of substrate (waste) utilized over a finite time period (usually a day) by a mass of organisms (X).

The second, more universally used parameter is the mean cell retention time,[1] θ_c, which is also known as the:

1. solids retention time, or
2. sludge age

and is defined by:

$$\theta_c = \frac{X}{dX/dt} = \frac{X_t}{(\Delta X/\Delta t)_t} \qquad \text{(A-6)}$$

where, dX/dt is the net growth rate of microorganisms.

In comparison, U is a measure of the rate of substrate (waste) utilization by a unit mass of organisms, while θ_c is a measure of the average retention time of organisms in the system.

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[1] The mean cell retention time is more easily measured.

The efficiency of treatment by a biological process is defined as:

$$E = \frac{100(S_0 - S_1)}{S_0} \qquad \text{(A-7)}$$

where E = treatment efficiency, percent
S_0 = influent waste concentration
S_1 = effluent waste concentration

The hydraulic retention time of a reactor is given by:

$$\theta = V/Q$$

where θ = hydraulic retention time
V = reactor volume
Q = volumetric flow rate through reactor.

Relationships describing steady state conditions in continuous flow biological treatment systems can be derived by performing mass balances on materials entering and leaving a system. Commonly used steady state models of suspended microbial waste treatment processes are shown in Figure A-1. Equations describing these systems are presented in Table A-1.

For the system without recycle, the hydraulic retention time is equal to the mean cell retention time and so directly determines process efficiency. In the recycle system, there is much opportunity for tradeoffs between reactor volume, mixed liquor concentration in the reactor, and settling tank or clarifier operation. Hydraulic retention time ($\theta = V/Q$) is not an independent parameter and can assume a range of values without affecting biological process performance. It is worth noting that longer hydraulic retention times do contribute to equalization capacity of the reactor and enhance the stability of the process against hydraulic shock loadings.

From Table A-1 the following functional relationships can be seen:

1. process efficiency (E) and effluent soluble substrate concentration (S_1) are dependent only upon the mean cell retention time (θ_c) and the biokinetic coefficients (K_s, m, q, k, and b).

2. organism, concentration (X) and sludge production (P_x) are dependent only on θ_c, the biokinetic coefficients, the volumetric flow rate of influent (Q) and the influent substrate (waste) concentration, S_o.

A.2.2 Effects of Flow Reduction

Reducing the influent volumetric flow rate (Q) will result in an increase of influent substrate concentration (S_o) if the mass of wastes involved is not changed. If effluent substrate concentrations (S_1) can be maintained at pre-flow reduction levels, then an increase in process efficiency (E) will be observed:

$$S_0 \propto 1/Q, \; E \propto S_o, \; S_1 = \text{constant} \qquad \text{(A-8)}$$

This increased efficiency has implications to the treatment dynamics. For a non-recycle system, lowering Q will increase the system hydraulic retention time (θ) and so the equivalent mean cell retention time (θ_c):

$$(\theta_c = \theta) \propto 1/Q, \; V = \text{constant} \qquad \text{(A-9)}$$

Adjusting the retention time in this non-recycle case establishes the microorganism concentration in the reactor (X) since influent substrate concentration (S_O) is defined from the mass waste load and volumetric flow rate (Q).

The apparent simplicity of effects of flow reduction on process operation must be qualified with a listing of limiting assumptions and observations:

1. All nutrients required for proper biological growth are present. The only limiting

substance is the organic matter needed for heterotrophic organism growth, or for autotrophic organisms, the inorganic energy source, pH and temperature are regulated for optimum growth.

2. Operational constraints limit the value of θ_c that can be practically employed. These constraints result from the higher concentrations of microorganisms which result from higher retention times and include; a) difficulty in mixing microorganisms in the reactor, b) oxygen mass transfer limitations, c) inadequate separation of microorganisms in the settling tank, and d) nutrient depletion effects.

It should also be noted that for an existing system, reducing the flow rates will result in the system being operated in a sub-optimal fashion, in terms of available reactor volume. For design purposes, reducing influent flow will affect required reactor volume in a multi-variate manner since θ_c, Q, X, and S_o in the equation for reactor volume V will all change:

$$V = \frac{YQ\theta_c(S_o - S_1)}{X(1 + b\theta_c)} \qquad \text{(A-10)}$$

For the recycle system shown in Figure A-1, a settling unit is added in which cells from the reactor are settled and then returned to the reactor. The existence of the settling unit requires two additional assumptions regarding the kinetics of the system. They are:

1. No waste stabilization occurs in the settling unit (a conservative assumption).
2. The mean cell residence time is computed independently of the settling tank volume. Only the reactor volume is used.

In a recycle system, the mean cell residence time is given by:

$$\theta_c = \frac{VX}{wX + (Q - w)X_c} \qquad \text{(A-11)}$$

where X_c = microorganism concentration in settling tank effluent. A properly operated unit will have a negligible X_c so that θ_c can be approximated as:

$$\theta_c \propto V/W \tag{A-12}$$

Hence in a recycle system, θ_c is independent of θ, the hydraulic retention time. This means that a longer θ_c, needed to obtain a low effluent substrate concentration (S_1) and thus a high efficiency, can be achieved with a short θ needed for system economy. Cell retention time is controlled by the rate of cell wastage from the reactor. It should be noted that several factors work to negate the complete independence of θ and θ_c. They are:

1. oxygen transfer rate in the reactor unit
2. proper settling unit operation
   settling characteristics of suspended solids in the mixed liquor.

Flow reductions will have a minimal effect on overall process operation, then, since the controlling parameter, θ_c, can be controlled by cell wastage procedures. The assumptions heretofore stated must, however, be kept in mind.

TABLE A-1

SUMMARY OF STEADY STATE RELATIONSHIPS FOR BIOLOGICAL WASTE TREATMENT WITH SUSPENSIONS OF MICROORGANISMS

CHARACTERISTIC	COMPLETE-MIX SYSTEM	
	Without Recycle	With Recycle
Specific Efficiency	$E_s = \frac{100(S_o - S_1)}{S_o}$	$E_s = \frac{100(S_o - S_1)}{S_o}$
Effluent Waste Concentration	$S_1 = \frac{K_s[1 + b(\theta_c)]}{\theta_c(Yk - b) - 1}$	$S_1 = \frac{K_s[1 + b(\theta_c)]}{\theta_c(Yk - b) - 1}$
Microorganism Concentration in Reactor	$X = \frac{Y(S_o - S_1)}{1 + b\theta_c}$	$X = \frac{Y(S_o - S_1)}{1 + b\theta_c} \frac{\theta c}{\theta}$
Excess Microorganism Production Rate (mass/time)	$P_x = \frac{YQ(S_o - S_1)}{1 + b\theta_c}$	$P_x = \frac{YQ(S_o - S_1)}{1 + b\theta_c}$
Hydraulic Retention Time (V/Q)	$\theta = \theta_c$	$\theta = \theta_c[1 + r - r(X_r/X)]$
Solid Retention Times General	$(\theta_c)^{-1} = \frac{YkS_1}{K_s + S_1} - b$	$(\theta_c)^{-1} = \frac{YkS_1}{K_s + S_1} - b$
Limiting Minimum	$[\theta_c^m]_{lim.} = (Yk - b)^{-1}$	$[\theta_c^m]_{lim.} = (Yk - b)^{-1}$

Source: A.W. Lawrence, "Modeling and Simulation of Slurry Biological Reactors," prepared for Mathematical Modeling In Environmental Engineering, Eighth Annual Workshop, Nassau, Bahamas, December 1972.

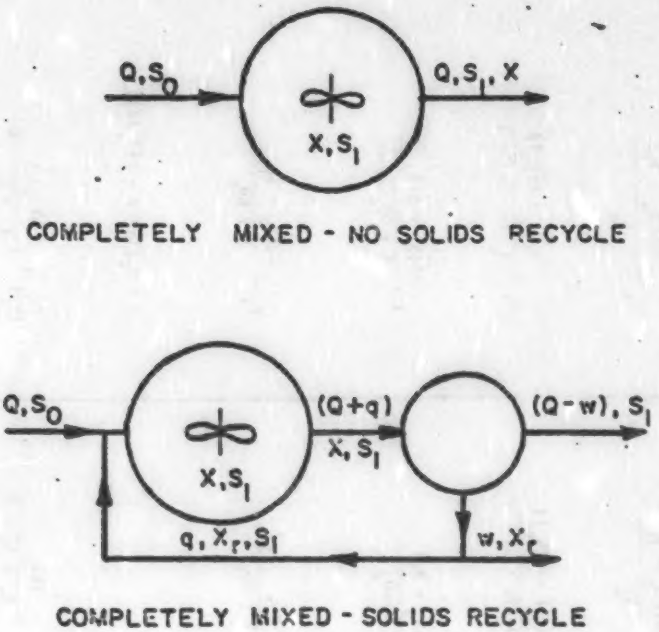
Q, S0
Q, S1, X
X, S1
COMPLETELY MIXED - NO SOLIDS RECYCLE
Q, S0
(Q+q)
X, S1
X, S1
(Q-w), S1
q, Xr, S1
w, Xr
COMPLETELY MIXED - SOLIDS RECYCLE

FIGURE A-1. THIS FIGURE SHOWS THE SCHEMATIC REPRESENTATION OF TWO BIOLOGICAL PROCESS FLOW SCHEMES.

APPENDIX B

INPUT DATA TO THE COMPUTER MODEL PAM

This appendix lists all input data relevant for the policy analysis model (PAM).

The water demand regional factors (R_n for Region n) are as follows:

REGION	WATER DEMAND FACTOR
I	1.0
II	0.61
III	1.05
IV	1.15
V	1.07
VI	1.23
VII	1.22

The water supply regional cost factors are as follows:

REGION	WATER SUPPLY COST FACTOR
I	1.0
II	1.02
III	0.93
IV	1.19
V	0.73
VI	0.92
VII	0.89

The water demand housing factors (h_i) that attempt to capture the sprinkling water demand variations among the three housing types are:

HOUSING TYPE	DEFINITION OF HOUSING UNITS	WATER DEMAND FACTOR
1	Single-family unit	1.33
2	2-5 family unit	1.00
3	Townhouse and Apartment Building	0.5

The house values (υ) for different income classes are:

INCOME CLASS	DEFINITION OF INCOME CLASS	HOUSING VALUES (in \$ x 10^{-3})
1	< \$6,000/year	13.9
2	\$6,000 - \$15,000/year	19.8
3	> \$15,000/year	39.0

The rate structures of the various pricing schemes for billing periods of two months are as follows (in ¢/thousand gallons):

PRICING SCHEME	LOW	MEDIUM	HIGH
IBR			
0-4,000 gallons	25	50	75
4,000-22,000 gallons	35	70	105
>22,000 gallons	45	90	135
DBR			
0-4,000 gallons	58	115	172
4,000-8,000 gallons	33	65	97
>8,000 gallons	23	45	67
UUR			
The whole range of consumption	30	60	90
FR			
The whole range of consumption	\$6	\$12	\$18